Environmental Management

of Energy from Biofuels and Biofeedstocks

James G. Speight
Kamel Singh

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Publishers at Scrivener
Martin Scrivener (martin@scrivenerpublishing.com)
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Preface

Biomass is a renewable resource, whose utilization has received great attention due to environmental considerations and the increasing demand for energy worldwide. Since the energy crises of the 1970s, many countries have become interested in biomass as a fuel source to expand the development of domestic and renewable energy sources, reduce the environmental impact of energy production, provide rural prosperity for its poor farmers and bolster a flat agricultural sector. Biomass energy (bioenergy) can be an important alternative in the future and a more sustainable energy. In fact, for large portions of the rural population of developing countries, and for the poorest section of urban populations, biomass is often the only available and affordable source of energy for satisfying basic needs as cooking and heating.

However, for a given feedstock, management includes several important issues that require attention: (1) sustainability, choice of feedstocks and markets (2) chemical composition of the biomass, conversion processes and technologies (3) availability of land and land use, and the earth's resources (4) the various environmental issues that accompany biomass cultivation and use (5) rural development, prosperity, employment for the poor and landless (6) biofuel life cycle (energy balance and energy efficiency, GHG (greenhouse gas) emissions) (7) policies, subsidies and (8) future for biofuels etc. Indeed, while many observers claim that biofuel production and use are an environmental benefit, this is not the case. Indeed, 1st generation biofuels have a multiplicity of ethical, political, social, economic and environmental concerns and are viewed as competing for agricultural production destined for food, feed, fibre and fertilizer. The main concerns are that production of 1st generation biofuels competes with food for feedstock and fertile land, potential availability is limited by soil fertility and per hectare yields (1 hectare = 2.47 acres) and that effective savings of carbon dioxide emissions and fossil energy consumption are limited by the high

energy input required for crop cultivation and conversion. Liquid biofuels made from sugar, starch and plant oils still represent the only large near-term substitute for petro-fuels and may offer some reprieve to countries grappling with rising oil prices, increasing national and global insecurity, climate instability and local as well as global pollution levels. The debate continues as to the effectiveness of biofuels in addressing such pressing problems.

The environmental risks associated with growing biomass for fuel production such as loss of wild habitat, loss of biodiversity and negative impacts on soil, air and water make the case for carefully managing biofuel production processes to minimize ecological impact. New energy crops, improved management practices (methods of cultivation and harvest), alternative farming methods (reduced soil erosion, improved soil quality, reduced water consumption, reduced susceptibility to pests and diseases (minimize usage of herbicides and pesticides) will critically engage the attention of the scientific community, governments and planners. Implementing policies and instruments (certifications and standards) for a sustainable biofuel market and the considerations for international trade must also be critically examined so all stakeholders are treated equitably and emerging producers have a say in the global debate.

The importance of the biofuel life cycle in terms of energy and fuel characteristics for some of the more commercially available biofuels such as ethanol, biodiesel, straight vegetable oils, animal fats, dimethyl ether (DME) and biomass to liquids (BtL), in addition to attributes as energy efficiency, engine and vehicle effects, and fuel consumption, must feature prominently in any discussion regarding a suitable substitute for petro-fuels and reducing greenhouse gases.

The social aspects of the management of biofuels (development of agriculture and rural areas as instruments for expanding markets and creating employment), the role of producing value-added products, the use of subsidies in the development of a biofuel economy and challenges as supplementing typically imported fuels, fuel vs. food debate, logistical concerns related to infrastructure, transport and delivery, and policies and regulations must also be critically engaged by stakeholders as the industry matures. Discussion must also include next generation biofuels, advances in the biorefinery concept, new vehicle technologies, market barriers and upcoming biofuel competitors to round out such a diverse topic.

Thus, the focus of the book is to present a historical overview, country perspectives, a description of the use of biomass to produce biofuels, the current and upcoming sources of biofuels, technologies and processes for

biofuel production, the various types of biofuels and, specifically, the ways and means to make biofuel production sustainable, economically feasible, minimize environmental damage and to deliver on its many promises. A large task for any alternative fuel in the early stages of its development. Greater public and private sector initiatives will be required to make biofuels mainstream and a credible alternative to petro-fuels.

James G. Speight, PhD, DSc, PhD
Laramie, Wyoming, USA

Kamel Singh BSc, MSc
St. Augustine, Trinidad and Tobago

September 2013.

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Fuels From Biomass

1.1 Introduction

Biomass is a renewable resource, whose utilization has received great attention due to environmental considerations and the increasing demands of energy worldwide. Since the energy crises of the 1970s, many countries have become interested in biomass as a fuel source to expand the development of domestic and renewable energy sources and reduce the environmental impacts of energy production (Seifried and Witzel, 2010). Biomass energy (bioenergy) can be an important alternative in the future as a more sustainable energy supply. Currently, it accounts for 35% of primary energy consumption in developing countries, raising the world total to 14% of primary energy consumption from bioenergy (Demirbaş, 2006; Ericsson and Nilsson, 2006; Speight, 2008; Nersesian, 2010; Speight, 2011a). It is the main energy source in a number of countries and regions (Hoogwijk et al., 2005). In fact, for large portions of the rural populations of developing countries, and for the poorest sections of urban populations, biomass is often the only available and affordable source of energy for basic needs such as cooking and heating (Demirbaş, 2006).

Biomass has the largest potential and is considered the best option to insure fuel supply in the future (Speight, 2008; Balat, 2011). As 90% of the world's population is expected to reside in developing countries by 2050, biomass energy is predicted to be a substantial energy feedstock and various energy scenarios suggest potential market shares of modern biomass of approximately 10% to 50% till the year 2050 (Hoogwijk et al., 2005).

Biomass, mainly in the form of wood, is the oldest form of energy used by humans. Traditionally, biomass has been utilized through direct combustion, and this process is still widely used in many parts of the developing world. In industrialized countries, the main biomass processes used in the future are expected to be powered by direct combustion of residues and wastes for electricity generation, bio-ethanol and biodiesel as liquid fuels, and combined heat and power production from energy crops (UNCTAD, 2008; NREL, 2009; Balat, 2011; Lee and Shah, 2013).

The most important biomass energy sources are wood and wood wastes, agricultural crops and their waste byproducts, municipal solid waste (MSW), animal wastes, waste from food processing, and aquatic plants and algae. The majority of biomass energy is produced from wood and wood wastes (64%), followed by MSW (24%), agricultural waste (5%), and landfill gases (5%) (Demirbaş, 2001).

Thus, energy management is not only related to resource management and economics but also to the environment and the ecology. With the depletion of fossil fuels, a gradual shift to renewable energy sources including biofuels is inevitable, but it is a matter of the timing of the shift and the preparation time before the shift (Speight, 2011b). However, extensive research and development efforts are required to make the renewable energy sources cost-effective, affordable and sustainable (Speight, 2011a). Coprocessing of petroleum residues, coal, biomass, and wastes (Speight, 2011a, 2011b, 2013a, 2013b, 2014) may generate cleaner fuels in the transition period from conventional to biofuels, which may extend the life span of petroleum use (Bower, 2009; Speight, 2011b).

However, for a given feedstock, the management of feedstocks includes several issues that require attention: (1) chemical composition of the biomass, (2) cultivation practices, (3) availability of land and land use practices, (4) use of resources, (5) energy balance, (6) emission of greenhouse gases, acidifying gases and ozone depletion gases, (7) absorption of minerals to water and soil, (8) injection of pesticides, (9) soil erosion, (10) contribution to biodiversity and landscape value losses, (11) farm-gate price of the biomass, (12) the cost of logistics (transport and storage of the biomass), (13) direct economic value of the feedstocks taking into account the co-products, (14) creation or maintain of employment,

and (15) water requirements and water availability (Gnansounou et al., 2005; Tampier et al., 2005).

Although the focus of this chapter is the production of biofuels from biomass, many people assume that very few bio-products are commercially viable. However, the commercialization of compounds derived from biomass is not unusual. A few examples include (1) furfaral, a precursor for nylon from oat, (2) vanillin from lignin, and (3) acetone and butanol from anaerobic fermentation (Ekman and Borjesson, 2011).

This chapter reviews the basic history of biofuels, the current and upcoming sources of biofuels, technologies and processes for biofuel production, and the various types of biofuels. Ways and means to make biofuel production economically feasible and minimize environmental damage are also covered.

1.2 The Growth of Biofuels

Biomass includes all biological products, such as wood and plants that contain stored-up energy that can be used to produce heat, electricity, and hot water. Biomass energy can also be derived from wastes such as (1) agriculture waste, (2) logging residues, (3) paper industry wastes, (4) building wastes, or (5) standing forests (pre-commercial thinning, imperfect commercial trees, and dead or dying trees) and energy crops (fast growing trees and grasses such as miscanthus, switchgrass, hemp, corn, poplar, willow, and sugarcane).

Although biomass, in the form of firewood, has been used throughout human history, its prevalence as a heat source declined when fossil fuel prices dropped. Recently, biomass has been considered anew due to improvements in biomass burning technology and the problems associated with fossil fuel use. Most biomass technology has involved and continues to involve the direct burning of biomass to produce energy. Other recently developed technologies include the following: (1) cofiring, when biomass is added to traditional fuel sources, such as coal and burned jointly, (2) the burning of landfill gases (methane and carbon dioxide) or gas from wastewater treatment plants, (3) biomass gasification in which the biomass is heated in the absence of oxygen to produce synthesis gas, which is burned, (4) liquid pyrolysis, where biomass is liquefied in the absence of oxygen and burned, and/or cogeneration, when biomass is burned to produce heat and electricity (Speight, 2008, 2011a, 2013a, 2013b).

As a result of the renewed and ever-increasing interest in biomass and biofuels, capturing the potential of biomass resources entails addressing

major challenges. Such obstacles include developing a reliable and sustainable feedstock supply, understanding and quantifying land use change and competition, and reducing costs for growing, recovering, and transporting feedstocks. Critical areas of research include developing (1) sustainable management and utilization options, systems, and practices to effectively integrate biomass production into ongoing forest management activities, (2) best management practices for sustainable expanded biomass removal, (3) new woody crops varieties that are fast-growing, efficient in using water and nutrients, and resistant to pests and environmental stresses, (4) science and technology for short rotation woody cropping systems – wood that is purpose-grown for use in energy applications, (5) improved harvest, collection, handling, and transportation systems for woody biomass, and (6) developing strategies to integrate forested systems into agricultural landscapes to provide services and income.

The creation of a sustainable bio-industry producing biofuels and bioproducts on a significant scale is critically dependent on having a large, sustainable supply of biomass with appropriate characteristics at a reasonable cost, cost-effective and efficient processes for converting wood to biofuels, chemicals, and other high-value products, and useful tools for decision-making and policy analysis (Giampietro and Mayumi, 2009).

This involves the consideration of issues such as (1) factors spurring growth in the biofuels market, (2) challenges to the wide-scale use of biofuels, (3) history of biofuels programs, and (4) current biofuel production.

1.2.1 Factors Spurring Growth in the Biofuels Market

Biofuels, through their local availability and versatility (solid, liquid, gas), are now increasingly important modern energy carriers (Soares Pinto, 2011). This has opened up new opportunities to address complex global issues such as, (1) rising oil prices and the subsequent cutting of imported oil, (2) national security concerns arising from political instability in oil exporting countries, (3) the desire to increase farm incomes, bolster agricultural industries and arrest deepening poverty in rural and agricultural areas, (4) new and improved bio-refining technologies, (5) government incentives sparking a new wave of investment, and (6) environmental preservation to combat rising climate instability, greenhouse gas emissions, and worsening local and global pollution levels.

Biofuel initiatives are gaining momentum in many countries (both developing and industrialized) as policy makers grapple to set environmental boundaries, ensure sustainability and assure social equity. The resurgent interest in biofuels has placed it high on the international

agenda, as it appears globally there is a growing confidence that biofuels are maturing rapidly.

Using the United States as the example, the US market for biofuels is based principally on ethanol consumption by a national fleet of gasoline-powered vehicles. Ethanol production in the USA has grown continuously since the end of the 1990s. Higher demand has driven a rapid increase in the number of ethanol production plants from fewer than 50 plants in 17 states producing approximately 1.4 billion gallons (1.4×10^9 gallons, 2.7 Mtoe) in 1998, to 204 installations in 29 states producing more than 13.2 billion gallons (26 Mtoe) in 2010.

Currently more than 90% of gasoline consumed in the USA contains up to 10% bioethanol. Nevertheless, to achieve the biofuel incorporation targets set out in the RFS2 (the Renewable Fuel Standard of 2009, which lays the foundation for achieving significant reductions of greenhouse gas emissions from the use of renewable fuels, for reducing imported petroleum, and encouraging the development and expansion of the US renewable fuels sector), it appears that widespread introduction of E15 will be required. Already adopted in some states, E15 is not yet fully authorized for use in vehicles manufactured before 2001, or in motorcycles.

The US biodiesel industry is younger, and produces much lower volumes than the US ethanol industry. It started at the beginning of the 2000-decade and, until 2004, production was limited, usage was purely domestic and there was no external market. Between 2005 and 2008, production increased significantly to meet strong growth in exports. Exports fell back significantly after 2009, following regulations introduced by the European Commission to counter excessively advantageous taxation in the USA.

The fact that the annual incorporation obligations specific to biodiesel (biodiesel) were not introduced in regulatory form until March 2010, resulted in falling consumption of biodiesel between 2008 and 2010. Future production levels should henceforth achieve the government target of 2.3 Mtoe (800 million gallons (Mtoe)) in 2011.

Although the USA is putting significant effort behind the deployment of new fuel technologies (the so-called second-generation ligno-cellulosic processes), the sectors already in operation, like corn-based ethanol and soya-based biodiesel, also continue to be well supported by investment programs and government subsidies. The (RFS2) consumption targets set for corn-based ethanol require an eventual contribution of 15 billion gallons (28 Mtoe), compared with current production capacity of 13.5 billion gallons (26 Mtoe).

In keeping with the initiatives to support biofuel production in the US, the exporting countries are generally those with abundant raw material

resources and the potential for industrial development of the sector (Brazil, Indonesia as well as other members of the Asia-Pacific Region, and possibly some African countries) and/or tax incentives to export products (like the USA). The importing countries are those that have regulatory targets in place for incorporating biofuels, but lack sufficient resources to achieve those targets (such as the USA and many European countries).

Nevertheless, economic factors may periodically disrupt supply or demand, forcing some countries to change their market balance. In 2010, worldwide biofuel trading volumes totaled 3.5 Mt (2.2 Mtoe) for ethanol and 2.6 Mt (2.3 Mtoe) for biodiesel. In terms of production levels, biodiesel is traded more actively than ethanol, with an export/production ratio of 15.7%, compared with just 5% for ethanol. Nevertheless, these global trends have fluctuated over time (IFP, 2012).

1.2.2 Challenges to the Wide-Scale Use Of Biofuels

Biofuels are currently the only form of renewable energy usable by the transport industry (IFP, 2012). As a direct substitute for oil, gas and coal, biomass should enable the production of fuels low in greenhouse gases emissions (greenhouse gas). Used essentially in blends with conventional fuels (concentrations of up to 10% are possible without engine modification), they can also be used pure or in higher concentrations (B30 or E85) by specially adapted vehicles.

In 2010, global consumption of biofuels represented 3% of total fuel consumption (i.e. 55 Mtoe; approximately 313,500,000 barrels of oil). This total figure for biofuels breaks down into 73% bioethanol (produced by fermenting sugar and usable in gasoline-powered engines) and 27% biodiesel (produced from vegetable oils and usable in diesel-powered engines).

Despite a number of key issues such as land use and competition for feedstocks supplies for traditional food and feed uses, global use of biofuels is expected to more than double from 2009 to 2015, according to a new global analysis released today by Hart's Global Biofuels Center. Leading the expansion is the United States with a growth of total biofuels use of more than 35%. Brazil will grow domestic supplies by 30% and more than double its export volume. Indonesia and Malaysia will more than double production of palm oil biodiesel, while Germany will remain the largest producer of biofuels in Europe.

There are several challenges to the use of biofuels and these include: (1) the competition for scarce resources that place additional strain on the life support systems of the earth, (2) the convergence of the energy, food,

fiber and feed markets that further complicate global investment decisions and will probably increase food prices – a trend that may be beneficial to farmers, but could make it more difficult to satisfy food needs of the world's urban poor, and (3) expanded cropping into new territory that could lead to soil erosion, aquifer depletion, and the loss of biologically rich ecosystems such as tropical rain forests, natural savannahs, grasslands, and woodlands. Government land use policy and implementation and enforcement will be critical in determining the net ecological impacts of expanded biofuels use.

Meeting these challenges will demand (1) employing new environmentally sustainable technologies (new crops and farming methods), (2) employing advanced conversion technologies, (3) the use of highly energy efficient vehicles, (4) the development of cellulosic ethanol derived from plant stalks, leaves and wood, (5) the use of synthetic fuels (such as diesel fuel) produced from a broader range of energy crops and waste streams (agricultural and forestry wastes, and switchgrass) using advanced biochemical and thermochemical conversion processes, and (6) the implementation of prudent and innovative government policy to steer the industry in the right direction.

1.2.3 History of Biofuels Programs

Humanity relied on wood (*bioenergy*) long before oil was discovered. Plant oils and sugars have been used to power automobiles for over a century. American inventor Samuel Morey used ethanol and turpentine in the first ICE as early as the 1820s. Nicholas Otto ran his first SI engines on ethanol and Rudolph Diesel used peanut oil in his prototype CI engines. Henry Ford's Model T could even be calibrated to run on a range of ethanol-gasoline blends. However in the early 1900s as the popularity of automobiles rose, the fuel market was flooded with cheap petroleum fuels. Following WW II (in the 1940s), cheap petroleum fuels swept the market, virtually eliminating biofuels.

However, the oil crises of the 1970s sparked renewed interest in alternative fuels. Brazil, which had maintained a small fuel ethanol industry since the 1930s, expedited a national ethanol program (Proalcool) to alleviate its great national debt and encourage agricultural production. After the 2nd oil crisis of 1979, the Brazilian government prioritized ethanol production, expanded sugarcane production, constructed new ethanol distilleries and facilitated the development of engine technology for ethanol-only cars. By the 1980s, this aggressive campaign to make ethanol a mainstream transportation fuel had succeeded in displacing almost

60% of the country's gasoline consumption. The Brazilian auto industry in 2003 introduced flexible fuel vehicles (FFVs), which run on any combination of gasoline or ethanol; this gave drivers the option to choose whichever of the fuels were cheaper. Consumer demand for such vehicles has surged and by early 2006 more than 75% of the cars sold in Brazil were flex fuel vehicles.

The US response was to launch its own ethanol programme using corn as feedstock and to produce a proportionally small but increasing amount of ethanol. The Brazilian and US ethanol industries still produce the vast majority of the world's fuel ethanol – almost 90% in 2005.

In China the government encouraged peasants to cultivate oil plants that would provide some assurance against disruptions in diesel fuel supplies but it abandoned these efforts after the price of oil fell in the mid 1980s.

In 1978 the Kenyan government initiated a programme to distil ethanol from sugarcane and began producing an E10 blend. Unfortunately, this programme failed due to drought, poor infrastructure and inconsistent policies.

Zimbabwe and Malawi initiated programs in 1980 and1982 respectively but only Malawi has consistently produced fuel ethanol since then.

In Europe a trade dispute triggered a rise in biodiesel production, starting in 1992. The EU agreed to prevent gluts in the international oilseeds market by confining production to just under 5 million hectares. The reserved acreage was used to grow feedstock for biodiesel production and with the help of EU government's subsidies and reduced taxes on biodiesel a new market for farmers was created. This initiative led to the rapid increase in European biodiesel production particularly in Germany.

Environmental standards are now one of the primary drivers for making biofuels mainstream. The United States Environmental Protection Agency now require US cities with high ozone levels to blend gasoline with fuel oxygenates (ethanol). In the 1990s and early 2000s MTBE, a common fuel oxygenate, was identified as a possible carcinogen that was contaminating ground water. Since then, most states passed laws to have it phased out, creating a surge in demand for US ethanol in the early 2000s.

1.2.4 Current Biofuel Production

A wide range of feedstocks are available globally for biofuel production including energy crops (e.g. Miscanthus, Jatropha, and Short Rotation

Coppice), wastes (e.g. waste oils, food processing wastes, etc.), agricultural residues (straw, corn stover, etc.), forestry residues and novel feedstocks, such as algae. The impact of both climate change and population growth mean there is increasing local and global competition for land, feedstocks and water for food production (crops and livestock), non-food crops (e.g. plant oils for soap production, timber for construction), and bioenergy (heat and power).

At the same time, biodiversity (species of plants and animals), which influence biofuels production, need to be conserved, and forested areas must be protected as they act as important habitats and carbon sinks. In other words, the forests store large amounts of carbon in vegetation and soil. If areas are cleared for logging, grazing, crop production or roads, the carbon is released into the atmosphere and habitat is lost.

The USA and Brazil dominate world ethanol production, creating 38.2 billion liters (1 liter = 0.264 US gallon)" in 2006. Close to half of the world's ethanol was produced in the US from corn, representing 2–3% of the country's non-diesel fuel. In 2005, many new ethanol production plants started operations or were either under construction or in the planning stages. US ethanol production capacity increased by 3 billion liters in 2005 with an additional 5.7 billion liters of new capacity under construction going into 2006. In 2010, the US produced 19.8 billion liters (Cherubini, 2010).

More than 40% of the global fuel ethanol was produced in Brazil from sugarcane, representing roughly 40% of the country's non-diesel fuel. The remainder came from the EU (Spain, Sweden, France, and Germany) made from sugar beets. China used corn, wheat, and sugarcane to produce ethanol, mainly for industrial use. India used sugarcane and cassava intermittently to produce fuel ethanol. Biodiesel has also seen strong growth in almost all of Europe, which comprised nearly 75% of total biofuel production in 2012. In 2006, the EU accounted for 73% of all biodiesel production worldwide, mainly from rapeseed and sunflower seeds. Germany accounted for 40% with the US, France, Italy making up the rest.

Worldwide biofuel production capabilities are changing, especially in the US. US biodiesel, mainly from soybeans, was 1.9M liters in 1995 but by 2005 it had jumped to 284 M liters and again in 2006, to 852M liters. In mid-2006, production capacity stood close to 1.2 billion liters from 42 facilities and more than 400 million liters per year of additional production capacity were under construction at 21 new plants. In Europe, 40 plants exist and their capacity is expected to grow rapidly both in Germany (a leader in world biodiesel production), Austria, Czech Republic, France,

Italy, Spain and Sweden. In fact, a number of countries have pursued initiatives to bring biofuels into the mainstream as part of their energy mix (Table 1.1).

Table 1.1 Directives, Initiatives, Programs, Expectations, Plans, Considerations, Policies to Foster Biofuel Development Internationally.

Country	Directives, Initiatives, Programs, Expectations, Plans, Considerations, Policies to Foster Biofuel Development Internationally
Japan	Permitted low-level ethanol blends in preparation for a possible blending mandate, with the long-term intention of replacing 20% of its oil demand with biofuels or GTL fuels by 2030.
Canada	45% of the country's gasoline consumption would contain 10% ethanol by 2010. Ontario set to be the centre of the ethanol programme where all fuels were expected to be E5 blends since 2007. Iogen Corporation operates a pilot plant to convert straw to ethanol using enzymatic technology and has now teamed up with DaimlerChrysler, Volkswagen and Shell to build a pre-commercial straw to ethanol plant in Europe.
EU	Desire for greater energy security as well as the requirements of the Kyoto Protocol, has set the goal of 5.75% of transportation needs from biofuels by 2010 in all member states. Adopted an ambitious Strategy for Biofuels with a range of potential market based, legislative and research measures to increase the production and use of biofuels. Germany and France have plans to expand both ethanol and biodiesel production, with the aim of achieving EU targets. Researchers at DaimlerChrysler, Volkswagen and Shell have collaborated to produce a marketable technology of a gasifier and F-T reactor to produce a liquid fuel (BtL) Stated goal to have 10% of transport sector being serviced by biofuels by 2020 (Cherubini and Ulgiati, 2010)

Country	Directives, Initiatives, Programs, Expectations, Plans, Considerations, Policies to Foster Biofuel Development Internationally
USA	High oil prices, agricultural lobbying prompted the enactment of the Renewable Fuel Standard (RFS), which will require the use of 28.4 B liters of biofuels for transportation by 2012. US government fleet vehicles that run on diesel fuel are now required to use B20 blends under new guidelines implementing the 1992 Energy Policy Act. Policy makers expect this number to be the floor, rather than a limit on biofuel production. Research into enzymes that could refine abundant low-value plant fibers into ethanol. Novozymes claimed in 2005 that they have discovered how to reduce the cost by 10-30 times and promised further reductions. Abengoa, a multinational ethanol company is already building a facility in Spain that will utilize these enzymes.
Brazil	Lessons learned from its highly successful fuel ethanol programme to be transferred to the country's biodiesel initiatives. All diesel fuel to contain 2% biodiesel by 2008, increasing to 5% in 2013. Through government initiatives it is hoped that poor farmers in the north and northeast receive much of the economic benefits of biodiesel production.
Columbia	As of 2006, the government plans to phase in 10% ethanol blends in all gasoline sold in cities with populations over 500,000.
Venezuela	As of 2006, the state oil company PDVSA supported the construction of 15 sugarcane distilleries over the next 5 years as the government plans to phase in a national E10 blending mandate.
Bolivia	As of 2006, 15 sugarcane distilleries were being constructed to support government initiatives to introduce an E25 blending mandate.

(*Continued*)

Table 1.1 *(Cont.)*

Country	**Directives, Initiatives, Programs, Expectations, Plans, Considerations, Policies to Foster Biofuel Development Internationally**
Costa Rica and Guatemala	Trial stages of expanding its sugarcane infrastructure to support its fuel ethanol initiatives.
Argentina, Mexico, Paraguay, Peru	Considering new biofuel programs
Thailand	To reduce the cost of its oil import bill and support its sugarcane and cassava growers the government has embarked on an ambitious plan to introduce 10% ethanol blends starting in 2007. Ethanol blending mandate has already increased the price of cassava and the government is reversing its sugarcane restriction policy to encourage more domestic production.
Philippines	The government proposes to mandate 2% biodiesel, to support its coconut growers and 5% ethanol by 2007. Legislators have been planning to introduce a biodiesel blending mandate to support the country's nearly 5M coconut farmers and an ethanol mandate to help prevent shrinking acreage in the sugarcane industry.
Malaysia and Indonesia	In the developing world Malaysia and Indonesia are rapidly expanding palm oil acreage; with the aim of satisfying European biodiesel demands (hope to boost exports by over 30% in the coming years).
India	Rejuvenated sugar ethanol programme calls for E5 blends throughout the country, a level the government plans to raise to E10 and E20 as the programme takes root.
China	The government is making E10 blends mandatory in 5 provinces that accounts for 16% of the nation's passenger cars.

Country	Directives, Initiatives, Programs, Expectations, Plans, Considerations, Policies to Foster Biofuel Development Internationally
Kenya, Malawi, Zimbabwe, Ghana, Ethiopia, Benin, Mozambique, Senegal, Guinea Bissau, Nigeria, South Africa	Corn producers in South Africa are using excess production as collateral to finance the construction of eight ethanol facilities, creating a long term additional market for the crop.
Australia	Sugarcane growers have experienced a 20% drop in the price of their sugar despite higher international prices and have turned to a domestic fuel ethanol programme to provide a more stable market.

1.3 Conventional Biomass Feedstocks

Generally, biomass is any naturally occurring biological or carbonaceous material that can be used as a fuel or can be used to produce fuel (biofuel). More recently the term biomass gas been applied to wastes such as (1) agriculture waste, (2) logging residues, (3) paper industry wastes, (4) building wastes, or (5) standing forests (pre-commercial thinning, imperfect commercial trees, and dead or dying trees) and energy crops (fast growing trees and grasses such as miscanthus, switchgrass, hemp, corn, poplar, willow, and sugarcane).

1.3.1 Fuels from Food Fiber and Feed Crops (1st Generation)

First generation biomass feedstocks commonly refer to those that are harvested for their sugar, starch and oil and converted into liquid fuels using conventional technology. Consequently, *first generation biofuels* are fuels such as ethanol and other products that are produced from sugar, starch, or vegetable oil.

Currently, the first generation processes for the production of ethanol from corn use only a small part of the corn plant. The corn kernels are taken from the corn plant and only the starch, which represents about 50% of the dry kernel mass, is transformed into ethanol. Two types of

second-generation processes are under development. The first type uses enzymes and yeast to convert the plant cellulose into ethanol while the second type uses pyrolysis to convert the whole plant to either a liquid bio-oil or synthesis gas. Second generation processes can also be used with plants such as grasses, wood or agricultural waste material such as straw. Second generation and later generation feedstocks (collectively known as *next generation biomass* feedstocks) are those harvested for their total biomass and whose fibers can only be converted into liquid biofuels using advanced technical processes.

This section will focus on the *first generation biomass* feedstocks: sugar crops (sugarcane, sugar beets, and sweet sorghum), starch crops (corn, wheat, barley, cassava, sorghum grain) and oilseed crops (rapeseed, soybean, palm oil, jatropha), and discuss production potentials and overall suitability for large scale production. Brief mention will be made of other oil sources for biodiesel (sunflower, mustard seed, waste vegetable oil (WVO), micro-algae and animal oils). Common products of these conventional biomass feedstocks are bioethanol, biomethanol, biodiesel, starch-derived biogas, and bioethers (EConvMgmt 2010p1412).

1.3.1.1 Sugar Crops

Although sugar crops had been known for some time, the sugar industry is believed to have begun in 710 AD and Egyptians were the first to establish the refined sugar industry, in the 9th and 10th Centuries, when the area under cane cultivation reached 75,000 feddans (1 feddan = 1.038 acres) and sugar was exported to Europe. Currently the three main sugar crops are cultivated in Egypt: (1) sugarcane, (2) sugar beet, and (3) sweet sorghum.

1.3.1.1.1 Sugarcane

Sugarcane is the main source for refined sugar and the molasses industry. In addition to consuming it fresh or crushing it into juice, the by-products from its refining are used as raw materials in the plywood and paper pulp industries. Molasses from sugarcane is used in the production of ethyl alcohol, active yeast, citric and acetic acid, and in dextrane, a replacement for plasma.

Sugarcane stalks are extremely rich in sugar and are currently the lowest cost source for ethanol. They produce large amounts of fiber in their leaves and stalks making them suited to 'co-harvesting', a significant source of cellulosic feedstock for bioenergy uses.

Currently, sugarcane provides over 40% of the world's fuel ethanol. The bulk is grown in two distinct regions of Brazil, the center-south region and

north-northeast region, which have different climates, production systems and harvesting periods. In 2010, Brazil produced 17.8 billion gallons of sugarcane based ethanol (Cherubini, 2010). The country's average yield is approximately 82.4t per hectare and the acreage under cultivation is approximately 5.5M hectares, of which 2.75M hectares (~50%) are used for ethanol production (Kaltner et al, 2005). The Brazilian cerrado, a biologically diverse area that is largely uncultivated, is by far the largest area remaining worldwide for expanding sugarcane production. It comprises highly diverse and sensitive ecosystems so a balance must be struck between environmental preservation and sugarcane expansion (Chapter 2, Section 2.5 Impact of Growing Biomass).

Sugarcane is grown in the world's tropical regions and countries that export raw sugar. Brazil, Australia, Thailand and Guatemala are probably best positioned to have extra cropland capacity for sugarcane ethanol production in the near term. Columbia, Cuba, the Philippines and Swaziland, may begin to produce ethanol for domestic and regional markets if there is a near term demand. Many of these countries are already in the process of forming significant biofuels programs. Unfortunately, in Cuba, at a time of increasing oil prices, sugarcane cultivation is declining and the country's biofuel aspirations could be jeopardized due to shortages in production equipment and fuel as well as poor primary resources and deficient technical operations for production and harvesting. A study concluded that sugarcane grown in tropical areas could produce enough fuel to displace 10% of global gasoline demand by 2020 (Fulton et al, 2004).

1.3.1.1.2 Sugar Beets

Sugar beet is a relatively new crop in many parts of the world. Due to limited water resources and a scarcity of land environmentally suitable for sugarcane cultivation, combined with an increasing demand for refined sugar, large-scale cultivation of sugar beet is under way. By-products from the refining process are used to produce nontraditional animal feeds.

Sugar beets serve as the primary feedstock for ethanol production in Europe. Sugar beet crops grown under temperate conditions, compared to sugarcane grown in the tropics, are more chemical and energy intensive and costly. The plant root must be processed to obtain the sugar and the harvesting and processing is a heavily mechanized process. Another concern is the potential for pests to survive in the soil. This means that crops cannot be cultivated more than once every three years on the same field. Since beets are more expensive than sugarcane for ethanol production, its economic sustainability depends on government protection from cheaper sugarcane imports.

1.3.1.2 Starchy Crops

By definition, starchy crops are those types of crops that contain starch (*amylum*) which is a high molecular weight carbohydrate (polysaccharide) consisting of a large number of glucose units joined by glycoside bonds.

Pure starch is a white, tasteless and odorless powder that is insoluble in cold water or alcohol and can be hydrolyzed to simple sugars using acids or enzymes, after which these can be fermented in the same way as those from sugar crops. Starch may be derived from grains such as wheat or maize, or from potatoes.

1.3.1.2.1 Corn

Corn is the second largest source of biofuel feedstock mainly because of its dominant role in the production of US fuel ethanol. It is grown predominantly in the 'corn belt' states of Illinois, Iowa, Minnesota, South Dakota, and Nebraska. In 2005 15% of US corn crop displaced 2–3% of the country's gasoline (RFA, 2005b). Modest ethanol production from corn also comes from Northeastern China and South Africa. Producing ethanol from corn requires huge amounts of synthetic nitrogenous fertilizers and herbicides need to be applied to the field and crop (which can lead to eutrophication in nearby surface water, affecting other plants and wildlife) and is more land intensive than sugarcane (with lower fuel yields per hectare).

Although the US produces amounts of ethanol comparable to Brazil, it uses approximately 2 times as much land (5M hectares compared to 2.7–3M hectares in Brazil). In addition to the amount of land that needs to be cultivated, an additional hydrolysis step is required to convert starch to fermentable sugars. However one major advantage of corn over sugarcane is its longer 'shelf life'. Corn can be stored for long periods after harvesting whereas sugarcane must be processed quickly (from 24 to 48 hours).

1.3.1.2.2 Sweet Sorghum

Sweet sorghum describes any of the many varieties of the sorghum plant, which has high sugar content. It is a type of grass that thrives better under drier and warmer conditions than many other crops. It is grown primarily for forage, silage, and syrup production (*golden syrup*).

The plant is currently undergoing evaluation as a commercial crop. By-products of sweet sorghum processing include fiber (used by the paper industry) and bagasse, used as fuel.

1.3.1.2.3 Wheat

Wheat is a cereal grain that is cultivated worldwide – world production of wheat is in excess of 704 million tons, making it the second most-produced

cereal after maize (817 million tons) and ahead of rice production (678 million tons) (FAOSTAT, 2012).

The ethanol yield per hectare (1 hectare = 2.47 acres) of wheat is lower than that of sugarcane and corn, like corn, only the kernel (which contains starch) is used. Most of the wheat produced is consumed as food, so little remains for fuel production. Wheat yields per hectare vary according to weather, averaging 5.7t in the EU (15 countries), 3.8t in China, 2.7t in India, and 2.4t in the US and Russia. Rye and barley are also used for ethanol production in Northern Europe as they are resistant to drier cooler conditions and acidic soils. Demand for rye as both a food and feed has declined in recent years (new ethanol plants have stimulated some additional planting).

1.3.1.2.4 Cassava

Cassava (*Manihot esculenta*), also called manioc, manioc root, yuca, balinghoy, mogo, mandioca, kamoteng and kahoy, a woody shrub of the Euphorbiaceae (spurge family) native to South America, is extensively cultivated as an annual crop in tropical and subtropical regions for its edible starchy, tuberous root, a major source of carbohydrates. It differs from the similarly spelled yucca, an unrelated fruit-bearing shrub in the Asparagaceae family. Cassava, when dried to a starchy, powdery (or pearly) extract is called tapioca and the fermented, flaky version is named *garri*.

Cassava is the third-largest source of food carbohydrates in the tropics, after rice and maize. Cassava is a major staple food in the developing world, providing a basic diet for over half a billion people. It is one of the most drought-tolerant crops, capable of growing on marginal soils.

Cassava is the most cultivated crop in sub-Saharan Africa. It is the second most grown crop in Africa overall, fourth in Southeast Asia, fifth in Latin America and the Caribbean and seventh in Asia. Although more than 60% of the world's cassava is grown in Africa, the highest yields are achieved in Asia due to lower disease prevalence, fewer pests and intensive crop management such as access to irrigation and fertilizers. Cassava has the advantage that it can be cultivated in areas with poor soil quality or that are susceptible to drought. Cassava was considered for ethanol production in Brazil during the 1980s, however, its yields were lower than that of sugarcane, it was more labor intensive to cultivate and the processing was considerably more complex. As a result, commercial production for ethanol was not pursued. However, in Thailand cassava is the cornerstone of its commercial ethanol programme. Similarly, Nigeria has placed cassava at the center of its planned ethanol program.

1.3.1.2.5 Sorghum Grain

Sorghum grain is a distant second to corn in the US for ethanol production. It is also grown in India, Sudan, Nigeria and Niger. Approximately 4% of the world's sorghum crop is converted to ethanol (mainly non-fuel for uses), 44% is used as feed, 43% for human consumption and 7% as a waste crop. The potential exists for the crop waste, which amounts to 3.8M tonnes per annum, to be put to the production of 'next generation' biofuels.

1.3.2.3 Oilseed Crops

Oilseed crops are grown primarily for the oil contained in the seeds. The oil content of small grains (such as wheat) is only 1 to 2%. Oilseeds range from approximately 20% w/w for soybeans to an excess of over 40% w/w for sunflowers and rapeseed (Canola). The major world sources of edible seed oils are soybeans, sunflowers, rapeseed, cotton and peanuts. Seed oils from flax (linseed) and castor beans are used for industrial purposes. Edible fats and oils are similar in molecular structure; however, fats are solid at room temperature, while oils are liquid.

Oil seed crops provide the primary feedstock for biodiesel. The major oil seeds cultivated are soybean (largest), rapeseed (dominant feedstock in Europe) and cottonseed. Other sources include sunflower, palm oil, and waste edible oils (Cherubini, 2010). In cooler climates oil seed crop yields are usually lower than starchy cereals as corn and wheat, however they require less processing and generally have favorable energy balances (Tampier et al., 2005). Oilseed crops grown in the tropics are highly productive. Oilseed species vary widely in their oil saturation and fatty acid content (this affects the properties of the biodiesel). Highly saturated oils produce a fuel with superior oxidative stability and higher cetane number (an indication of combustion efficiency) but with poor low temperature properties. For these reasons vegetable oils with a high percentage of saturation is suited for warmer climates.

1.3.2.3.1 Rapeseed

Rapeseed (*Brassica napus*), also known as rape, oilseed rape, rapa, rappi, rapaseed (and, in the case of one particular group of cultivars: canola), is a bright yellow flowering member of the family *Brassicaceae* (mustard or cabbage family). The name derives from the Latin for turnip (*rāpa* or *rāpum*) and was first recorded in English texts at the end of the 14th Century. Older writers usually distinguished the turnip and rapeseed by the adjectives *round* and *long* (*-rooted*), respectively.

Rapeseed is commonly grown in rotation with cereal crops, is relatively productive and accounts for the highest output of biodiesel per hectare in the EU when compared to soybean and sunflower seeds. As previously noted, in

cooler climates yields are lower (quantity of fuel per hectare less) when compared to starchy crops. Two key factors that limit the expansion of rapeseed are at least two years should be left between the cultivation of rapeseed and other cruciferous crops (broccoli, cauliflower, cabbage, Brussels sprouts) and soil quality" to "Two key factors that limit the expansion of rapeseed are: (1) at least two years should be left between the cultivation of rapeseed and other cruciferous crops (broccoli, cauliflower, cabbage, Brussels sprouts), and (2) soil quality. In Europe biodiesel producers have special arrangements with their governments to produce a certain amount of feedstock on set aside land for fuel production. About half of this production is in Germany; but France, the Czech Republic and Poland are also significant growers.

1.3.2.3.2 Soybeans

The soybean (US) or soya bean (UK) (*Glycine max*) is a species of legume that is native to East Asia, widely grown for its edible bean that has numerous uses. The UN Food and Agricultural Organization (FAO) classify the plant as an oilseed rather than a pulse, a crop harvested solely for the dry seed.

Soybeans are the dominant oilseed crop cultivated worldwide (world production ~ 215M tonnes (1 tonne = 1.102 US tons) in 2004–2005; 57% of major oilseed production; Brazil, USA and Argentina are the major producers). Soybeans when compared to other oilseed crops generate a relatively low yield of biodiesel per hectare; however they have a number of noteworthy advantages. Soybeans (1) can be grown in both temperate and tropical regions (2) are a nitrogen fixing crop (replenish soil nitrogen and require less fertilizer input, more favorable fossil energy balance) (3) may be grown in rotation with corn in the US and sugarcane in Brazil (duo-cropping). Soybean harvesting is heavily mechanized and dominated by large multinational agro-processors (Cargill and ADM of the US). Out of total soybean production, 86% is used in food manufacturing, 8% is consumed directly as human food or animal feed and only a small portion is transformed into fuels. However, this is all set to change as Brazil is now proceeding apace to develop its national biodiesel programme.

1.3.2.3.3 Oil Palm

The oil palm (*Elaeis guineensis*) is a species of palm commonly called *African oil palm* or *macaw-fat* and is the principal source of palm oil. The species is native to west and southwest Africa, growing between Angola and The Gambia – the name *guineensis* refers to one of its countries of origin, Guinea. The closely related American oil palm *Elaeis oleifera* is also used to a lesser extent to produce palm oil, and a more distantly related palm *Attalea maripa* is another oil-producing palm.

Palm yields a very high level of oil per hectare making it attractive for biodiesel. Malaysia, Indonesia and Nigeria are large-scale producers. Brazil

accounts for a small share of the world's palm oil, however, it has a significant potential for expansion. Production is expected to grow considerably as Brazil ramps up its national biodiesel initiatives. The demand for palm biodiesel is expected to increase rapidly in EU since the Netherlands and the UK are the major importers.

1.3.2.3.4 Jatropha

Jatropha is a genus of flowering plants in the spurge family, Euphorbiaceae, and is a common starting feedstock for the production of biodiesel (Pandey et al., 2012). Most spurges are herbs, but some, especially in the tropics, are shrubs or trees while others are succulent and resemble cacti. The family contains approximately 170 species and most of these are native to the Americas, with 66 species found in the Old World. Mature plants produce separate male and female flowers. As with many members of the family Euphorbiaceae, *Jatropha* contains compounds that are highly toxic.

Jatropha curcas is an oilseed crop that grows well on marginal and semiarid land; the bushes can be harvested twice annually, are rarely browsed by livestock and remain productive for decades. In India, approximately 64M hectares of land are classified as wasteland or uncultivated land and jatropha has been identified as one of the most promising feedstocks for commercial biodiesel production. The crop is also particularly well suited for fuel use at the small-scale village level. Seed yields are dependent upon a number of factors (1) germplasm quality (2) plantation practices and (iii) climatic conditions. These will be the drivers for economic and commercial viability of jatropha becoming mainstream for the Indian biodiesel industry.

D1 Oils, a British company aiming to cultivate biodiesel in the developing world, has chosen jatropha as its primary feedstock due to the plant's high oil content, its ability to tolerate a wide range of climates and its productive lifespan of as much as 30 years (D1 Oils, 2006). As crop yields are improved, Indian researchers estimate that by 2012, as much as 15B liters of biodiesel could be produced by cultivating the crop on 11M hectares of wasteland (Mandal, 2005). Further work is needed to overcome the challenges in making jatropha mainstream.

1.3.2.3.5 Oilseed Crops and Tree Based Oilseeds

Other plants may be considered for the production of biodiesel and in some cases are already widely planted (Table 1.2). Beyond these common plant oils, more than 100 native Brazilian species (mainly palm tree species) and 300 different Indian tree species have been identified as having potential to produce oil bearing seeds for biodiesel production. Given the demand for vegetable oil as food, identifying non-edible species (jatropha,

Table 1.2 Alternate Plant Sources of Biodiesel.

Feedstock	**Supporting Notes**
Sunflower	Higher yield of biodiesel per area when compared to soybeans and a yield similar to rapeseed. It is the world's fifth largest oilseed crop and accounts for most of the remaining biodiesel production in Europe after rapeseed.
Cottonseed	The world's third largest oilseed crop is predominantly grown in India, Pakistan and US (together they account for 45% of world production).
Peanut	The world's fourth largest oilseed crop and accounts for 8.7% of major oilseed production. Major producers are China, India, US (70% of world production).
Mustard Seed	Provides a potentially valuable non-food feedstock. The plant's roots, leaves and stems breakdown in the soil into a variety of active but biodegradable chemicals, which provide a pesticide effect. Extraction of the plant oil leaves a meal (residual press cake) with a strong market potential for an environmentally friendly organic pesticide. To create a viable biofuels feedstock the plant will probably have to be genetically engineered to increase oil production and to increase the effectiveness of the residue for pesticide use.
Coconut	High yielding feedstock that produces highly saturated oil and is the favored feedstock for the Philippines biodiesel industry. Studies have shown that vehicles running on coco-biodiesel reduced exhaust emissions by as much as 60% and increased mileage by 1-2 km per liter due to increased oxygenation, even with a 1% minimum blend.
Castor Oil	Identified as the next most promising species for Brazil's biodiesel programme after palm oil, the growing is labor intensive and could provide jobs to poor farming communities in the north eastern regions of the country. India is the largest producer and exporter of castor oil followed by China and Brazil.
Waste Vegetable Oil	Soybean, rape, palm and coconut are the waste oils commonly used in biodiesel production. Before waste vegetable oil can be used it must be purified by filtering out residues and neutralization of acids produced by high temperatures. China produces most of its biodiesel from waste vegetable oil between 40,000 – 60,000 tons of cooking oil per annum.

pongamia, melia-neem, and shorea-sal) that can be grown on soils unsuitable for food crops is of major interest.

1.4 Challenges to Conventional Feedstocks

The main advantages of conventional feedstocks are their easy conversion to biofuel because of their high oil or sugar content (Cherubini, 2010). 1st generation biomass feedstocks (starch, sugar, plant oil) that current technologies can convert into ethanol and biodiesel will dominate the biofuels industry in the near term, however these will eventually give way to cellulosic feedstocks. This is because 1st generation biofuels have ethical, political, and environmental concerns (Cherubini, 2010). The main concerns are that production of 1st generation biofuels competes with food for feedstock and fertile land, potential availability is limited by soil fertility and per hectare yields and effective savings of CO_2 emissions and fossil energy consumption are limited by high energy input required for crop cultivation and conversion (Cherubini, 2010).

As stated before, the main advantage of first generation biofuel feedstocks are their easy conversions to biofuel because of high sugar or oil content (Cherubini, 2010). However, some of the current feedstocks have much greater biofuel potential than others. In general, crops grown in the tropics can produce larger quantities of fuel per hectare than those grown in cooler climates (sugarcane in Brazil vs. corn in the US or rapeseed in EU) in addition, the land use ratio in temperate climates vs. tropical is higher (agricultural residues, forest residues or perennial energy crops not taken into account).

In the EU, approximately 20% of the rapeseed crop goes to biodiesel production displacing only 1% of diesel fuel (the EU was unable to meet its biofuel target of 5.75% for transport fuels by 2010). Likewise, soybeans are constrained by comparatively low yields, higher yielding tropical oilseeds have greater promise to use land more efficiently; Malaysia and Indonesia are expected to ramp up production of palm oil to offset shortfalls in Europe for rapeseed. Like Brazil, where sugarcane expansion will likely encroach on the cerrado (natural savannahs), large palm oil plantations in Southeast Asia are blamed for displacing large tracts of natural forests; governments in producer countries must develop land use policies to maintain the balance between conservation and biofuel production.

Modern agricultural practices (mechanization, fertilizers, pesticides, research (hybridization), government price support policies, investment in new equipment (for cultivating and harvesting etc.) have dramatically

increased crop yields and nowhere this is more evident than in the developed world with corn and wheat. The areas with the greatest potential for crop yields using modern agricultural practices are in the developing world, where traditional farming methods are less productive and farms are generally small scale without the benefit of mechanization, sufficient chemical inputs and biotechnology. Additional gains are expected to come from genetic breeding which is transforming production by making available genetically altered varieties of corn, soybeans, sugarcane and other crops. The breeding of hybrids and crops that can grow in close proximity has helped achieve higher corn yields and genetic modification promise to push the envelope even further.

Biotech corn hybrids now account for over 40% of the total planted acreage in the US and in Brazil yields of soybeans and sugarcane have increased through breeding and genetic modifications, increased use of fertilizers and pesticides. Plant breeding has also boosted the yields of oil palm (new hybrids show promise of even higher yields). More dramatic genetic modifications may bring still higher yields, however, this promise could be short lived by a lack of public acceptance for genetically modified crops and intensified energy crop cultivation.

1.5 Fuels from Crop Residues, Wood and Dedicated Energy Crops

The next generation of biofuels will be produced from lignocellulosic materials. Cellulosic biomass from wood, tall grasses and forestry and crop residues are estimated to be 10^{10} million tons (47 EJ energy value) worldwide (Cherubini and Ulgiati, 2010). They are expected to significantly contribute to the 'next generation' of biomass feedstock for fuel production as new technologies become more economical and mainstream. It is expected that lower cost residue and waste sources of cellulosic biomass will provide the 'next generation' feedstock for biofuels, with cellulosic energy crops expected to supply additional feedstock and expanding substantially in the medium and long term. The use of waste biomass is an attractive proposition as it creates value by displacing fossil fuels with material that would otherwise have been left to decompose and no additional land for cropping is required. Cellulosic biomass from fast growing perennial energy crops, such as short rotation woody crops (SRWC) and tall grass crops can be grown on poorer soils and sloping land where production of conventional food crops is not desirable due to erosion concerns. The extensive root systems that remain in place with these energy crops help to prevent erosion

and increase carbon storage in soil. However, if high biomass yields are to be expected the soil quality should be marginal to good with sufficient water supply.

Because cellulosic biomasses are more difficult to breakdown and convert to liquid fuels, this makes them (1) more robust in handling – there are fewer costs for maintaining feedstock quality compared to many food crops, and (2) easier to store for longer periods of time (less deterioration than sugar based feedstocks). In addition, a greater percentage of the plant is used, meaning perennial energy crops can supply much more biomass per hectare since the entire biomass growth can be used compared to conventional sugar, starch and oilseed crops where only a fraction of the plant material is used (Cherubini, 2010).

Concerns about using agricultural residues include affecting soil organic matter turnover, soil erosion, crop yields and nitrogen oxide emissions from soil (Cherubini and Ulgiati, 2010). Moreover, even though cellulosic biomass is considered more robust in handling, this inherent bulk makes it very difficult to transport. For example, to produce 3.78 million liters of ethanol, you would need 1.33 million tons of biomass/year (Thorsell, et al., 2004). Thus, the costs from fuels from biomass will depend on the costs of harvesting and delivery to a large extent, and on production and conversion (Huang, et al., 2010). Additional concerns include identifying feedstock(s) that can consistently service the large demand for fuel when the much said feedstocks are typically subject to seasonality and discrete geographic availability (Fitzpatrick, et al., 2010).

Furthermore, most processes and technologies are in the pre-commercial, research stage and much investment in research and development, demonstration, and deployment will be necessary to replace first generation biofuels (Cherubini, 2010; Demirbaş, 2009).

1.5.1 Characteristics of Cellulosic Biomass

The physical characteristics of cellulosic biomass are useful in differentiating the various types of biomass and their compatibility for producing different biofuels. Cellulosic biomass has three primary components: cellulose, hemicelluloses and lignin. Cellulose has a strong molecular structure made from long chains of glucose molecules (six carbon sugars, C_6). Hemicellulose is a relatively amorphous component that is easier to breakdown with chemicals and/or heat than cellulose; it contains a mix of six-carbon (C_6) and five-carbon (C_5) sugars.

Lignin is essentially the glue that provides the overall rigidity to the structure of the plants and trees (trees typically have more lignin, which

makes them able to grow taller than grasses). For different types of plants and trees, these three components of biomass are present in varying proportions; a typical range is 40–55% cellulose, 20–40% hemicellulose and 10–25% lignin. Different technologies for producing biofuels from cellulosic feedstocks use different components of the biomass (Table 1.3).

The chemical content of the feedstock is important in determining its suitability for different conversion processes. Agricultural residues, such as sugarcane leaves, tend to be bulkier (lighter weight) and typically have greater amounts of ash than do woody crops such as poplar. This feedstock tends to be more difficulty to gasify. Thus there has been more of a focus on using crop residues or tall grass energy crops for enzymatic conversion to ethanol, particularly since they also tend to have a higher intrinsic sugar content and smaller amount of lignin.

In contrast, woody crops, because of their higher lignin content, are considered somewhat more attractive feedstocks for gasification and conversion to synthetic diesel fuel. Furthermore, soft woods have lower hemicellulose content, and the best bacterial conversion of bioethanol for hemicelluloses is ten times slower compared to cellulose (Demirbas, 2009; Kaparaju, et al., 2009). However, it makes good economic sense to utilize the cheapest and most available feedstock in a region. Biomass feedstocks that have a higher potassium or ash content are a problem for gasification technology since these components can create (or contain)

Table 1.3 Technologies for Producing Biofuels from Cellulosic Feedstocks Use Different Components of Biomass.

Conversion Process	**Component of biomass**	**Products**
Enzymatic conversion technology	Processes the core sugar components of cellulose and hemicellulose	Ethanol
Combustion and chemical conversion	Lignin	Boiler fuel, various chemicals, fuel additives, adhesives etc.
Gasification	Cellulose, hemicellulose, lignin	Syngas which can be used to produce liquid fuel such as synthetic diesel and/or other fuels and chemicals

compounds that melt at the higher gasification temperatures, leading to potential problems such as slagging or fouling of heat transfer surfaces. While these challenges are not insurmountable, they do constrain use of these feedstocks in a gasifier-based system (whereas enzymatic systems will typically be less affected by potassium and ash content). Ash that melts at a lower temperature can also be a concern for gasification systems since it tends to be easier to clean up solid particles than sticky half melted or liquefied material.

1.5.2 Biomass Residues and Organic Wastes

Biomass residues with potential energy uses are diverse and are classified as primary, secondary and tertiary residues and wastes (available as a by-product of other activities) as opposed to biomass that is specially cultivated for energy purposes.

Primary residues are produced during the production of food crops and forest products (straw, corn stalks and leaves, or wood thinning from commercial forestry). Such biomass is available *in the field* and must be collected to be available for further use.

Secondary residues are generated during the processing of biomass for production of food products or biomass materials. They include nutshells, sugarcane bagasse and sawdust and are the by-product of agro-processing, saw mills, and paper mills (pulp mills).

Tertiary residues become available after a biomass-derived commodity has been used. A diversity of waste streams is part of this category from the biodegradable organic fraction in MSW to waste and demolition wood, and sludge.

Biomass residues and wastes are linked with a complexity of markets and many residues can be used as fodder, fertilizer, soil conditioner or as raw material for a variety of manufactured products (particleboard, medium density fiberboard (MDF) and recycled paper). Availability and market prices of biomass residues and wastes generally depends upon a number of factors, including market demand, local and international markets for various raw materials and the type of waste treatment technology deployed for the remaining material. The latter is particularly relevant when 'tipping fees' are charged to dispose of the waste, giving some organic waste streams a (theoretical) negative value. Typically the net availability of organic wastes and residues can fluctuate and is influenced not only by market developments, but also the variability in weather conditions (causing high and low production years in agriculture) and other factors.

The physical and chemical characteristics of biomass resources also vary widely. Sewage sludge, manure from livestock farms and residues from food processing having a moisture content of approximately 60 - 70% w/w are more suited for biogas rather than ethanol or biodiesel. Other streams may contain heavy metals, chlorine, sulfur or nitrogen such different properties are important in selecting a suitable conversion technology.

1.5.3 Wood Residues

Unlike most other industries, the forest products industries are fortunate to be able to use their waste to help meet their energy needs. In mechanical wood processing the greater part of the thermal energy requirements can be met from the available residues, in fact, the sawmilling industry has the potential to produce both a surplus of heat and electricity and therefore could support other energy deficient conversion processes in an integrated complex producing, for example, lumber, plywood and particleboard or, in the rural areas, supplying energy for the needs of the surrounding community.

1.5.3.1 Forest Residues

Thinning (removal of undergrowth) from forests in the form of small diameter trees through under storey management of the forest floor helps to improve the health and productivity of the forest. This undergrowth could be used in biomass to liquid (BtL) fuel applications. Some amount of treetops and limbs that result from logging activities may also be suited as a supply of wood for biofuel production. The amount of woody material that should remain in the forest for habitat and carbon storage must be evaluated before any is removed. Wood from pest or storm damaged forests could also be a potential source of biomass for biofuel production.

1.5.3.2 Industrial and Urban Woody Residue

Much of the wood residues from the lumber industry provide the energy for the production processes (drying and cogeneration of heat and power), some of this wood residue could be diverted to biofuel production. The pulp and paper industry tends to use much of its wood waste as boiler fuel. The 'black liquor,' a by-product of the pulping process, apart from its use as a boiler fuel could be considered a feedstock for ethanol production as it is comprised of hemicelluloses (a mixture of C_5 and C_6 fermentable sugars). Wood from tree trimmings (backyards, right of ways) have competing uses as the production of mulch, electric power generation or thermal energy needs, however, some of this could be put into biofuel production.

1.5.3.3 Municipal Solid Waste

Municipal solid waste (MSW) contains a mix of cellulosic waste material including wood, paper, cardboard and waste fabrics. Since tipping fees are usually associated with disposal, it could provide a supply of low or 'negative cost' source of biomass feedstock for cellulose to biofuels facilities in urban areas (may be faced with the challenge to overcome legal barriers and public reluctance for establishing waste processing facilities in populated areas).

1.5.4 Crop Residues

Stems, leaves from conventional food crop harvests represent a substantial quantity of cellulosic biomass produced annually. It is predicted that 1.3 billion dry tons of biomass can be made available by small changes to land use and agricultural and forestry practices (Huang, et al., 2010). Normally this remains in the field and fulfills the important functions of (1) providing protection from erosion (2) providing benefits such as micronutrient supplies, soil organic matter and (3) enhanced soil 'tilth' (texture, structure, pore spacing in soil). However, in places where the land is relatively flat and/or where *conservation tillage* is used, a portion of the crop residue may be harvested. 'No till cultivation' (practiced on 23% of US cropland), where the soil is left undisturbed from harvest to planting, can potentially yield substantial amounts of crop residue that could be safely removed without increasing soil erosion, while maintaining soil structure and nutrients and not negatively impacting soil carbon levels (sound environmental and conservation practices). For example, in the US it is anticipated that 'no till cultivation' may allow harvesting as much as 75% of corn stover (stalks, cobs and leaves) and this may represent one of the best near term options for abundant cellulosic feedstock for ethanol production.

In Canada and Europe, wheat straw is a more abundant potential cellulosic feedstock. There are long-term economic and environmental concerns associated with the removal of large quantities of residues from croplands (reduced soil quality, promote erosion, loss of soil carbon etc.), which in turn lowers crop productivity and profitability. On other soils some level of removal can be sustained and even be beneficial, as such guidelines are necessary to ensure that removal of residual biomass is done in a sustainable manner.

In Brazil where more than 80% of the sugarcane is harvested manually, fields are burnt as part of crop management to make harvesting safer and

more productive. Burning causes considerable air pollution; the state of Sao Paulo has set deadlines for eliminating the practice and mechanized harvesting to be used (stands at ~25%). As technologies for converting cellulose to biofuels become mainstay, the tips and leaves (cellulosic field residue) from sugarcane harvesting will contribute significantly to the feedstocks available for biofuel production while facilitating reductions in air pollution caused by the burning of cane fields. In addition, the bagasse residues left after extracting sugar from the cane stalks further enhance the supply of cellulose available for ethanol production. The lignin residues that remain after processing the bagasse could then be used as boiler fuel, process heat and for electricity production. From research done in the US, it is estimated that the combined total supply of sustainable residues (agricultural, MSW and animal fats) is about 175 million dry tonnes per year.

In the same way hybridization is used to increase crop yields in corn and wheat for food production, the technology could be used to increase the amount of stems and leaves produced in crops (a source of cellulosic biomass for biofuel production). It is possible to do selective breeding of starch, sugar and oilseed crops, where new varieties could be specifically developed to increase the amount of cellulose (stem and leaf volume) allowing for significant cellulose harvesting along with the primary food crop (creating a benefit to farmers). It may be possible to modify crop cultivation and management approaches to increase the amount of cellulosic biomass that can be harvested by increasing plant spacing densities, however, the downside may be food yields will be decreased. Nonetheless, here lies the conundrum: is fuel, feed, fiber or food more important, and how should the balance to be struck?

As cellulosic biomass becomes mainstream for biofuel programs new approaches for planting more than one crop per year on farmland could significantly increase the amount of biomass produced per hectare. In food crop production the goal has been to obtain maximum yields of the end 'fruit' of the plant cycle, however 'double cropping', an entirely new strategy, can be used for crop planting where winter wheat crops planted in the late autumn could be harvested much earlier in the following year for their cellulose (stems and leaves) and put into cellulosic biofuel production. A second crop could then be planted (such as nitrogen fixing legumes) early enough in the year to mature for autumn harvesting. Crop combinations and planting sequences need to be determined to maximize the output and farmer returns. The best combination may be to produce cellulose, or a combination of cellulose and food crops, depending on climate and markets for food or fuel.

1.5.5 Energy Crops

Cellulosic biomass could also be produced from dedicated plantations of energy crops based on perennial herbaceous plant species (various tall grass species) and with the use of *short rotation woody crops* (SRWC), often referred to as *fast growing woody crops* (FGWC) (Downing et al., 1995). Eucalyptus has been grown for pulp markets and charcoal in Brazil. In the US and Europe poplar has been grown for fiber (pulp and paper industry), however the evaluation of suitable energy crops is still at its early stages compared to efforts in hybridization, genetic breeding (modification) for conventional food crops, tremendous opportunities exist to use plant science and agronomy to increase biomass yields. Energy crops, apart from increasing biomass yields, provide the benefit of moving land use away from intensive annual crop production to perennial herbaceous species or to SRWC leading to an increase in the soils organic matter over time, the development of root systems that provide protection against soil erosion, minimized use of fertilizers and pesticides and requiring less overall energy for crop management (not necessary to plough each year for planting).

Willow trees have been identified as a species suited for short rotation woody crops in temperate climates; they achieve high biomass yields using a *short rotation coppice* (SRC) approach. SRC entails harvesting the aboveground growth of young trees and the vigorous new growth of shoots and branches are collected every few years. In the case of willow, new growth is harvested every 2 to 5 years over a period of 20 to 25 years. Yields have increased substantially due to genetics and breeding (yields for some varieties have doubled). Hybrid poplar trees in temperate regions are suited to SRC energy crop applications.

In Brazil during the 1970s-1980s, short rotation coppice was practiced using eucalyptus trees. Tree stands were harvested every 5 to 7 years for up to three rotations before replanting; pests and diseases were a problem and more resistant hybrid species were introduced. Tall grass species (miscanthus, switchgrass and reed canary grass) are potential perennial crops that are attracting the interest of researchers in both the US and Europe. Experts believe breeding could result in at least a 2x increase in the productivity of energy grasses. In varieties of Bermuda grass and Pensacola Baha grass, yields have increased 2 to 7 fold. Commercial experience in SR-willow has been gained in the US and Sweden and to lesser extent in the UK. In Eastern Europe major interest is being shown in growing willow trees as an energy crop (conditions are well suited and production costs are lower at this time). SR hybrid poplar is appropriate for delivering biomaterial, energy and other products.

So far, there has been only limited commercial experience with miscanthus (in Europe), and the breeding potential of the species has hardly been explored.

Energy crops may also provide a more suitable habitat for some forms of wildlife when compared to conventional annual farm crops, the reason being that not all vegetation is removed each year. In addition, the density and height of energy crop vegetation is likely to be greater than conventional annual farm crops. To reduce the impact on wildlife, harvesting could be undertaken during non-nesting periods and in alternating strips (animals can move to an adjacent strip of the crop area that will not be disturbed). Research is needed to determine whether the mixing of varied grass or tree types could be allowed on energy plantations in an effort to add variety to the vegetative landscape. Special considerations regarding harvesting and conversion technology that could accommodate for a variation in feedstock would need to be taken into account. This added variety in energy crop species may decrease the maximum crop yields that are achieved; however, cost benefit analyses could help to determine the impacts on the feedstock production costs in comparison to the wildlife habitat benefits provided by added plant diversity.

1.5.6 Micro-Algae

Many researchers consider fuel from micro-algae to be a third generation fuel (Demirbaş, 2009). Micro-algae are microscopic single cell aquatic plants with the potential to produce large quantities of lipids (40 to 50% w/w oil) suited for biodiesel production. Using only sunlight, carbon dioxide, and nutrients, algae can synthesize and accumulate large quantities of neutral lipids, carbohydrates, and other valuable co-products (Singh and Olsen, 2011). Furthermore, the biomass can be fermented to provide ethanol, biogas, and protein-rich feed for human and animal consumption (Figure 1.1) (Singh, et al., 2011). Micro-algae are further considered attractive due to rapid growth rate, high CO_2 absorption and uptake rate and comparatively low land usage (Singh and Olsen, 2011).

Micro-algae can be grown in arid and semi-arid regions with poor soil quality, with a per hectare yield estimated to be many times greater than that of even tropical oilseeds. Algae can also be grown in saline water (polluted aquifers or the ocean), which have few competing uses in agriculture, forestry, industry or municipalities. Furthermore, algae can grow in wastewater, thus giving it the ability to address treatment, utilization, and disposal concerns (Singh and Olsen, 2011). Potential algae-derived biodiesel yields range from 5,000 to 100,000 L/ha/a (Singh and Olsen, 2011).

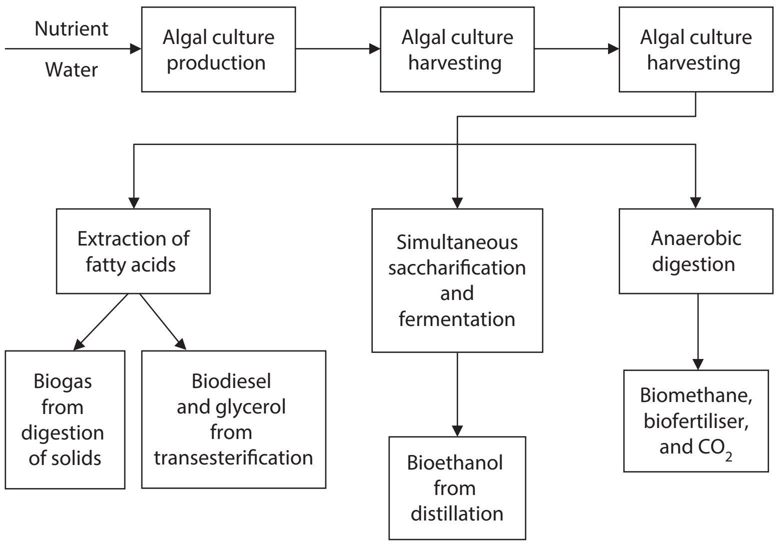

Figure 1.1 Algal Synthesis of Various Biofuels.

Algae feedstocks received early attention from the US National Renewable Energy Laboratory (NREL) in the 1980s and interest resurged based on their potential for cultivation near coal, petroleum and natural gas power plants. The emissions from such plants – CO_2 and NO_X – are the primary nutrients for growing micro-algae. This provides the opportunity for the algae to turn pollutants into lipids. Efforts at the MIT resulted in a promising technology for using micro-algae to clean up power plant emissions. GreenFuel, a private startup company was working to commercialize this technology and proposed such micro-algae colonies could reduce NO_x levels by some 80% and CO_2 by 30–40% while also producing a large quantity of raw algae biomass. Unfortunately, the firm succumbed to the credit crunch in the US and was shutdown in May 2009. Another pilot plant in Iowa, USA found that micro-algae can be grown on the CO_2 emitted from the conversions of corn to ethanol, but that the large heating requirements made the plant commercially unviable (Rosenberg, et al., 2011).

The most economically feasible and environmentally friendly conditions for growing micro-algae for energy purposes is still being investigated, the two main systems being open ponds and photo bioreactors (Singh, et al., 2011). Furthermore, lipid recovery is proving quite challenging, as high amounts of water need to be removed from the algae before conventional transesterification methods can be used (BioresTech 2011p26). Researchers

believe that the most feasible means for significant energy and cost savings would be a biodiesel production process that obviates biomass drying and organic solvent use for oil extraction (Singh and Olsen, 2011). Attempts to commercialise algal fuel production must also harmonize the challenge of finding large scale culture systems that balance light utilization efficiency, the ability to control temperature, hyrodyanamic stress placed on algae, the ability to maintain the culture unialgal and/or axenic and the ease of scale up to achieve economically acceptable outcomes (Singh, et al., 2011). Thus, the cost of cultivating algae is likely to make it uneconomical in the near term.

1.6 Technologies for Converting Biomass into Liquid Fuels

Scientific efforts have shown that it is possible to produce a variety of liquid biofuels from cellulosic biomass ('next generation' feedstock); however its cost is not competitive with petro-fuels, even with recent price hikes. Government and industry sponsored efforts are rigorously pursuing initiatives to lower production costs by improving conversion technologies to take advantage of this expanding resource base. This section will focus on the technology options and prospects for implementation. Cellulosic biomass is naturally resistant to being broken down into its 3 major constituents (cellulose, hemi-cellulose and lignin) when compared to first generation feedstocks (sugar, starch, plant oils), which are more easily converted to fermentable sugars. Thus while the cost of cellulosic feedstocks is expected to be lower, the difficulty in conversion to liquid fuels means the technologies are prone to be more expensive. Multiple steps are also required for conversion into a liquid fuel. Early studies have indicated that 6–10% of energy in biomass is utilized in feedstock preparation (Hernandez, 2011). The two primary conversion pathways are thermochemical and biochemical.

1.6.1 Thermochemical Conversion

These technologies typically use high temperatures and pressure to depolymerise lignocelluloses into small molecular weight organic and inorganic compounds which can be transformed into hydrocarbons, alcohols, aromatics, and other organics (Hernandez, 2011).

1.6.1.1 Gasification

The two major thermochemical pathways for converting biomass to gaseous and liquid fuels are gasification and pyrolysis. In gasification the biomass is thermally decomposed at a high temperature in an oxygen starved environment to prevent the combustible gases from burning. This synthesis gas (syngas – a mixture of carbon monoxide, carbon dioxide, hydrogen and methane) is converted to a liquid fuel as synthetic diesel using Fischer-Tropsch (F-T) technology (advanced catalyst conversion). However, the gasification Fischer-Tropsch conversion is expensive. In principle, numerous process configurations exist for the gasification of biomass to fuels. These configurations depend upon the gasifier type, the gas cleaning process, the product fuel and whether electricity is cogenerated using part of the syngas output from the gasifier (Lee et al., 2007). A key advantage of gasification Fischer-Tropsch is that it can convert all of the organic matter into gases and then liquids including lignin (difficult for enzymes to convert) and as a result, it has the potential to produce more fuel per tonne of biomass.

In the US, Brazil and Europe a number of pilot and demonstration plants for conversion of biomass to fuels have been started. Nonetheless, lower petroleum prices, depressed methanol prices, high capital costs and keeping the equipment free of tar, fine particles, alkali compounds and halogens threaten such efforts and must be overcome for the technology to reach commercialization. The dirty syngas can clog filters, poison catalysts and corrode the gas turbine, thus gas cleaning is an important requirement for successful and reliable plant operations.

1.6.1.2 Pyrolysis

Pyrolysis also uses high temperature in the absence of oxygen to convert the biomass into liquid 'bio-oil', solid charcoal and light gases similar to syngas. Depending on the operating conditions of temperature, heating rate, particle size and solid residence time, pyrolysis can be classified as conventional, fast or, flash. For example, if bio-oil production is to be maximized fast or flash pyrolysis is used, the biomass is heated to 500C for about 10 seconds. Pyrolysis temperatures are about 475C, whereas gasification is done at temperatures ranging from 600–1100C.

Several technical challenges must be overcome before biomass pyrolysis becomes mainstream and a source of large-scale energy. Bio-oil is moderately acidic, temperature sensitive and highly viscous with water content ranging 20–25% this leads to storage and engine problems; if they are to be considered as transportation fuel, further downstream processing is

necessary. Char and alkali metals must be removed (otherwise they may damage the engine) as they do not mix well with petroleum products and are best suited as fuel for stationary electric power or thermal applications (boilers, stationary diesel engines, industrial combustion turbines and Stirling engines) rather than transportation fuel. Biomass can also be converted to liquid oil by direct hydrothermal liquefaction (intermediate pyrolysis in the presence of water).

Pyrolysis is yet to be accepted as mainstream and as a result only small facilities are in operation. Ensyn Technologies and DynaMotive Energy Systems in Vancouver, Canada are actively developing and pursuing pyrolysis technologies in North America. In Europe, the Biomass Technology Group (BTG) located in the Netherlands is doing the same. For hydrothermal liquefaction, technology developers are Changing World Technologies (West Hampstead, New York), EnerTech Environmental Inc. (Atlanta Georgia) and Biofuel BV (Heemskerk, The Netherlands).

1.6.2 Biochemical Conversion

Biochemical conversion (enzymatic hydrolysis and microbial digestion) involves breaking down the biomass into cellulose, hemicellulose and lignin and converting the cellulose and hemicellulose components into fermentable sugars, followed by the use of yeast or specialized bacteria to convert the sugars to ethanol. This pathway requires a pre-treatment step (steam, acid, ammonia) to break down the biomass into liquid slurry. Using acid to hydrolyze lignocellulosic fibers tends to degrade too much of the hemicellulose sugars before they can be fermented into ethanol, causing low yields (Badger, 2002). This makes this method uneconomical when compared to the hydrolysis of starches or the fermentation of sugars and is being phased out. The slurry comprises hemicellulose – a mix of C_5 and C_6 sugars, cellulose (more difficult to breakdown into its sugars) and lignin. Cellulase enzymes hold promise for the breakdown of cellulose to glucose and the fermentation organisms for conversion of glucose to alcohol are readily available.

The C_5 sugars have required the development of customized organisms to enable the conversion to ethanol since 1/3 or more of the total carbohydrate content of typical biomass is comprised of C_5 sugars and normal yeasts are unable to ferment C_5 ones. With advances in biotechnology it is possible to customize and enhance the performance of enzymes for specialized conversion applications. The emphasis has been on improving fermentation organisms or improving the performance of the cellulase enzymes (cellulose glucose) and reducing costs. The development of

several new strains of enteric bacteria (*Esherichia coli* and *Klebsiella oxytoca*), thermophillic bacteria, mesophillic bacterium (*Zymomonas mobilis*) and yeast for the conversion of C_5 sugars to ethanol holds promise. Researchers are also developing variations and combinations of thermochemical and biochemical pathways for converting biomass into useful energy products.

1.6.3 Emerging Developments in Conversion Technology

Advances in cellulosic conversion technologies are improving the relative competiveness of cellulosic refining procedures against petroleum; the US and the EU have been the primary drivers for these initiatives. The US focus has been on biochemical pathways and the EU has concentrated on thermochemical involving integrated gasification and F-T synthesis processes.

1.6.3.1 Biochemical Technologies

The US DOE through the NREL has pursued the development of cheaper enzymes for the conversion of cellulose to sugars (cellulases) and cheaper microorganisms for the conversion of C_5 and C_6 sugars in hemicellulose. Biotechnology companies Novozymes, Genencor, Iogen and Dyadic are the major players in the development of the conversion pathways. The processing of lignocelluloses consists of 4 biologically mediated steps: (1) the production of cellulose (2) cellulase mediated hydrolysis of cellulose (3) fermentation of C_6 sugars (hexoses) and (4) fermentation of C_5 sugars (pentoses). These events can be combined to some extent: (1) separate hydrolysis and fermentation (SHF) where the 4 events are carried out separately, (2) simultaneous saccaharification and fermentation (SSF) where hydrolysis and conventional fermentation are combined into one process step and (3) saccaharification and conventional fermentation are combined with the fermentation of C_5 sugars in simultaneous saccaharification and co-fermentation (SSCF). SHF, SSF, SSCF all feature a dedicated process step for cellulase production, and (4) consolidated bio-processing (CBP) where all four biologically mediated events are combined into one process step, eliminating the dedicated cellulase production step. CBP holds the promise of offering the lowest cost in the long run. This kind of processing is at a much earlier stage of its development compared to the others.

Processes that show promise for the effective pre-treatment of lignocellulose include dilute acid, steam or hot water, ammonia, lime and other

agents. Research in this area is ongoing and one has not yet emerged as a clear-cut choice since each one has its own advantages.

1.6.3.2 Thermochemical Technologies

Much of the work in gasification and F-T synthesis has taken place in Europe. Opportunities exist for reducing the cost of the gasification pathway through technological advances by consolidating gasification, gas cleaning and/or gas processing (steam methane reforming and water gas shift) in a single vessel and developing large-scale, pressurized oxygen-blown gasifiers (Lee et al., 2007). Researchers in Europe and the US are also developing more efficient catalysts and better methods of cleaning and preparing syngas for producing different products (NREL, 2005). Gasifiers with combined unit operations have the potential to reduce cost. Researchers are also seeking out new markets for the many chemical by-products of gasification and F-T synthesis to help drive down fuel costs. Research work is ongoing to develop pyrolysis pathways for producing biofuels including new variations of 'hydrous' pyrolysis that can process wet biomass without pre-drying. The major players are Royal Dutch Shell, Changing World Technologies and FZK in Germany.

1.6.3.3 Outlook for Biochemical and Thermochemical Technologies

Of the two conversion pathways for cellulosic conversion, the bio-chemical route appears to be closer to large-scale implementation because the facilities are less capital intensive and economical even on a small scale (Hamelinck and Faaij, 2006). Demonstration facilities and commercial facilities are being constructed that use advanced biological methods to refine cellulose to ethanol. Biotechnology firm Iogen is using the bacterium Zymomonas mobilis to ferment C_5 sugars in hemicellulose to ethanol from wheat residue at its Ottawa plant. The Spanish firm Abengoa is using cheap enzymes developed by Novozymes to digest corn stover and BC International has combined conventional ethanol production with conversion of sugarcane residues using E.coli bacteria. Colusa Biomass Energy Corp has developed a process for converting rice hulls to ethanol. In Europe, Sun Opta Inc. proposed the first commercial cellulosic ethanol plant in Spain using technology licensed from Abengoa.

Although they are not as close to commercial viability, gasification and F-T are progressing strongly. Gasification is better able to handle a wide variety of feedstocks than enzymatic processes and permits the conversion of a greater fraction of feedstock carbon to liquid fuels. Biomass could also be combined with coal and co-gasified – an approach that has caught

the attention of Chinese planners who have shown interest in developing biomass-to-liquid technology by co-gasifying biomass and coal.

The technology is progressing towards cellulosic conversion facilities being integrated with conventional biofuel production facilities. One of the key challenges faced by 'next generation' biomass feedstock will be the expense associated with harvesting and collecting vast quantities, however, existing production facilities are already processing large quantities of biomass (high fiber by-products of starch based ethanol facilities, dry distillers grain (DDG) and at sugar based conversion facilities, bagasse and beet pulp). This convenient feedstock can be transferred to nearby facilities for conversion of this cellulosic mass to fuels.

Previous models for producing liquid fuels from lignocellulosic feedstock assumed that both cellulose and hemicellulose would have to be converted to fermentable sugars or the expense of collecting and harvesting would be too great. However, the availability of large quantities of low-value cellulosic biomass at integrated facilities could make it economical to convert the biomass-to-liquid fuel and the current conversion facilities could eventually evolve into biorefineries.

1.7 The Biorefinery Concept

Plants are very effective chemical mini-factories or refineries insofar as they produce chemicals by specific pathways. The chemicals they produce are usually essential manufacture (called metabolites) including sugars and amino acids that are essential for the growth of the plant, as well as more complex compounds. Biorefining offers a key method to accessing the integrated production of chemicals, materials and fuels. The biorefinery concept is analogous to that of an oil refinery (Speight and Ozum, 2002; Hsu and Robinson, 2006; Gary et al., 2007; Speight, 2014).

In a manner similar to the petroleum refinery, a biorefinery would integrate a variety of conversion processes to produce multiple product streams such as motor fuels and other chemicals from biomass. In short, a biorefinery would combine the essential technologies to transform biological raw materials into a range of industrially useful intermediates. However, the type of biorefinery would have to be differentiated by the character of the feedstock. For example, the *crop biorefinery* would use raw materials such as cereals or maize and the *lignocellulose biorefinery* would use raw material with high cellulose content, such as straw, wood and paper waste.

In addition, a variety of techniques can be employed to obtain different product portfolios of bulk chemicals, fuels and materials.

Biotechnology-based conversion processes can be used to ferment the biomass carbohydrate content into sugars that can then be further processed. As one example, the fermentation path to lactic acid shows promise as a route to biodegradable plastics. An alternative is to employ thermochemical conversion processes, which use pyrolysis or gasification of biomass to produce a hydrogen-rich synthesis gas that can be used in a wide range of chemical processes. Thus, a biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power and chemicals from biomass. The biorefinery concept is analogous to the petroleum refinery, which produces multiple fuels and products from petroleum (Speight and Ozum, 2002; Hsu and Robinson, 2006; Gary et al., 2007; Speight, 2014).

A biorefinery can have two or more options for the production of biofuels from wood and other biomass materials (Speight, 2011a). There is the (1) bioconversion, (2) thermal conversion, and (3) thermochemical conversion. Each of these options has merits but selection is dependent on the feedstock and the desired product slate.

The biorefinery concept where fuels and chemicals and power are co-produced is the model proposed for future biofuel production (Figure 1.2) (Fitzpatrick, et al., 2010; Kaparaju, et al., 2009; Liu, et al., 2012). The concept is similar to a petroleum refinery where fuels and chemicals are produced concurrently. Although electricity and heat can be provided by numerous renewable alternatives, biomass refineries are considered the only viable alternative for transportation fuels and chemicals (Cherubini, 2010). The three main drivers for using biomass in a biorefinery are climate change, energy security, and rural development (Cherubini, 2010). Biorefineries are either categorized by their inputs or major processes (Demirbas, 2009; Uihlein and Schebek, 2009). When categorised by inputs, they are lignocelluloses feedstock biorefinery, whole-crop biorefinery and green biorefinery. When categorised by process, they are biosyngas-based refinery, pyrolysis-based refinery, hydrothermal-based refinery and fermentation-based refinery.

Currently, refineries that utilize lignocellulosic feedstocks are considered the most promising because of the high availability of feedstock and low prices (Uihlein and Schebek, 2009). Other popular crops for biorefineries are alge and rapeseed. Rapeseed is considered a favourable bioenergy crop because it lends itself well to the biorefinery concept. The oil from the seeds can be used for biodiesel production and the rapeseed straw is a lignocellulosic material that can be converted to sugars via pretreatment and hydrolysis. These sugars can then be converted to biofuels by fermentation (Luo, et al., 2011). The effluents can also be used to produce additional

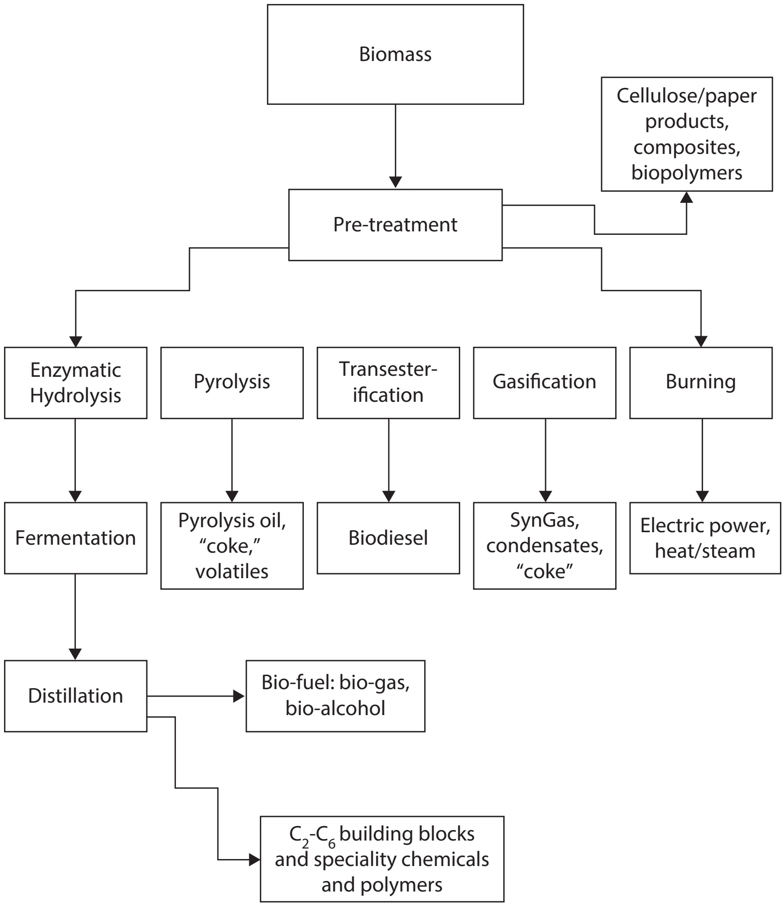

Figure 1.2 The Biorefinery Concept.

biofuels such as biohydrogen and methane via fermentation and the waste solids can be used as fertiliser. By utilising the biorefinery concept with rapeseed, calculated bioenergy recovery efficiency is increased from 20% to 60% (Luo, et al., 2011).

Notwithstanding anticipated synergies between the production of chemicals and energy (fuel and power) from biomass, one complicating factor is the size of potential markets for organic chemicals, which are small in comparison to markets for liquid fuels. Chemical co-products for biorefinery production must be carefully identified so as not to exceed the market demands, bearing in mind large quantities of liquid fuels are produced at these facilities. From an economic standpoint, they must produce multiple products that take can take advantage of the differences in

biomass components and intermediates and maximise the value derived from the biomass feedstock according to the market situation and biomass availability (BioresTech, 2011 p. 1433). Fuels will represent the bulk of production, however, chemicals and other materials will generate the profits (similar to conventional oil refineries where the flow of fuels leaving is in excess of 25 times the flow leaving as chemicals). In the case of *wet milling,* ranges of co-products (high-fructose corn syrup, high protein animal feedstock and specialty chemicals) are produced. Even though most bio-based products are made via the biological pathway, gasification and F-T synthesis also have the potential to co-produce a wide range of materials. F-T synthesis could probably produce all the hydrocarbons produced by petroleum refineries; however, the economics are unlikely to be the same for all products.

Future biorefineries will benefit from their ability to mimic the energy efficiency of modern oil refining and theoretical LCAs of biorefineries indicate that they will only be competitive with conventional refineries if process technologies are improved (Uihlein and Schebek, 2009). Furthermore, as integration levels in a biorefinery increase, so do the economic and production advantages (Demirbas, 2009; Huang, et al., 2010). For example, the paper and pulp industry is considered a promising candidate for integrated refineries as they have the potential to increase pulping capacity, additional revenue and profits, and the lowering of their greenhouse gas emissions (Huang, et al., 2010).

The technical barriers include cost of production, difficulties in harvesting and storing material grown, transportation costs, provision of nutrients and the control of pests and disease (Demirbas, 2009). Non-technical barriers include restrictions or prior claims of land use and the environmental and ecological effects of large areas of monoculture (Demirbas, 2009). Furthermore, a life cycle assessment of crop residue based biorefinery indicates that greenhouse gas emissions reduced by approximately 50% and more than 80% of non-renewable energy can be saved but that it will have higher eutrophication potential (Tampier et al., 2005; Cherubini and Ulgiati, 2010). Biorefineries will also have to figure out how to treat the large amounts of wastewater that will be necessary and to reuse the residual organics (Kaparaju, et al., 2009). Another key aspect will be heat integration (heat available from some unit operations can be used to meet heat requirements of other operations within the process), which allows heat to be re-used hereby reducing auxiliary energy inputs to the process. Notwithstanding the numerous potential disadvantages, a number of demonstration plants are either running or being planned (Table 1.4).

Table 1.4 Biorefinery Demonstration Plants (Demirbaş, 2009).

Name/Lead Company	Product	Planned or Actual Capacity (million gallons)
Abengoa Bioenergy[1]	lignocellulosic ethanol	25
Alico[1]	ethanol, electricity, ammonia, hydrogen	7.5
Berenium[1]	cellulosic ethanol	1.5
Blue Fire ethanol[1]	cellulosic ethanol	32
Choren[1]	biofuels and FT liquids	1.5
Ecofin, LLC[1]	corncob ethanol	1.3
Flambeau river[1]	biofuels and FT liquids	6.5
Flambeau[1]	lignocellulosic ethanol	14.2
ICM, Inc[1]	lignocellulosic ethanol	1.5
Iogen[1]	cellulosic ethanol	18
Lignol Innovations[1]	cellulosic ethanol	2.5
Mascoma[1]	cellulosic ethanol	0.5
New Page[1]	biofuels and FT liquids	12.8
Pacific Ethanol[1]	lignocellulosic ethanol	2.7
Poet[1]	corn ethanol	65
Range fuels[1]	biofuels and FT liquids	1.2
Royal Nedalco[1]	cellulosic ethanol	60
RSE Pulp[1]	cellulosic ethanol	2.3

1.8 Outlook for Cellulosic Liquid Fuels

Despite their promise, cellulosic conversion technologies are still probably at least 8 to 15 years away from supplying a significant portion of the world's liquid fuels. Biochemical pathways appear likely to begin significant commercial expansion in the next 8–10 years and thermochemical Fischer-Tropsch pathways are expected to begin such expansion in the next 10 to 15 years. Such timeframes will depend on funding, support for

commercialization and government willingness to engage with the challenges of biofuel programs in a meaningful way that that will benefit the population. Society will also need to be willing to invest in developing these technologies, as a period of development and government support is necessary to push them over the threshold into economic viability. A combination of these approaches appears to be more promising than doing either alone. Researchers will need to continue reducing the cost of producing valuable enzymes and improving on the technology of F-T gasifiers and cleanliness of syngas. The promise of cellulosic biofuels will also hinge on government support to risk averse investors who will be required to build a large number of cellulosic conversion plants (cost and risk of building new conversion facilities may hamper the development of 'next generation' fuels as a new cellulosic biofuel plant requires a larger capital expenditure than a conventional biofuel production plant) and petroleum prices remaining high enough for such operations to remain competitive. Cellulosic biofuels are still likely to remain more expensive than conventional first generation biofuels for some time but could be cheaper than petroleum if prices remain high. Even though the technologies appear promising and viable in providing a growing share of the global fuel supply, it will take a long time to ramp up to current petroleum fuel infrastructure levels and to compete with petroleum fuels.

1.9 Biofuels

As defined elsewhere in this chapter, a biofuel is a fuel that uses energy from carbon fixation and are produced a biomass conversion process, which can be any one of three processes (1) thermal conversion, (2) chemical conversion, and (3) biochemical conversion.

1.9.1 Ethanol from Sugars

Sugarcane, sugar beets and sweet sorghum all contain a large proportion of simple sugars and are common examples of sugar crops that are used as feedstock for producing fuel ethanol. Once the sugars have been squeezed out they can be fermented easily into ethanol. Starchy crops as corn, wheat and cassava must be hydrolyzed into sugar prior to fermentation. Under close-to-anaerobic conditions the sugar in plants ferment into acids and alcohols (ethanol). However, yeast has been used for thousands of years to accelerate the process. Ethanol production usually starts by grinding the feedstock to extract the juice, which contains

the dissolved sugars, as is the case for sugarcane and sugar beets or the starch as is the case of corn, which is then converted to sugar (hydrolysis step). The sugar is fed to yeast held under anaerobic conditions. The yeast produces enzymes that digest the sugar ($C_6H_{12}O_6$), yielding several products, including lactic acid, hydrogen, carbon dioxide (CO_2) and ethanol (C_2H_5OH). Brazilian distilleries are the most significant producers of ethanol from fermentable sugars and the fermentation units are usually part of an existing sugarcane mill producing various grades of sugar, molasses, CO_2 and bagasse. Advances in fermentation have led to the "continuous fermentation" process (recycling of yeast) a marked improvement over the traditional "single batch" process, which suffered from being slow and inefficient.

1.9.2 Ethanol from Starches

Ethanol from starchy crops such as corn, wheat and cassava requires a hydrolysis step to break down the polymers (thousands of sugar molecules long) into simple sugars (monomers); this saccaharification step requires additional energy and adds to the cost of ethanol production. The two common pre-treatment steps used for hydrolyzing starch into sugar are *wet milling* and *dry milling*.

In *wet milling* grains are soaked in a weak sulphurous acid solution to separate the starch rich endosperm from the high protein germ and the high fiber husks. Wet mills are usually large and produce a range of co-products such as corn oil, gluten feed, germ meal, starches, dextrin and sweeteners, which comprise more than a 25% of the economic output of the wet mill in addition to ethanol. In *dry milling* the unprocessed heterogeneous grains are ground down to granules, these mills require less investment and produce fewer co-products (dry distillers grain, DDG), a fibrous high protein residue (28% w/w protein) that is sold primarily as cattle feed. Dry mills have the advantage of being less costly and have lower complexity, however, wet mills offer greater flexibility and diversity and more closely resemble the bio-refinery of the future.

1.9.3 Fuel Ethanol

Fuel ethanol must be distilled to a purity of 95 to 99.8% v/v ethanol (initially the weak beer contains 5 to 12% v/v ethanol). The water content depends on the fuel specification for a particular application. Ethanol blended with gasoline should have < 1% trace of water to prevent engine problems. 'Neat' (100% v/v) ethanol used in warm climates may contain

traces of water since freezing does not occur. In Brazil 'neat' ethanol may contain up to 4% v/v water.

A liter of ethanol contains about 2/3 the energy of a liter of gasoline. However ethanol because of its high octane rating when blended with gasoline improves engine performance by reducing the likelihood of knocks (uncontrolled combustion in engine cylinders). Ethanol (C_2H_5OH,) is an oxygenated fuel because of the presence of oxygen in the molecular structure and this oxygen can improve combustion and help to reduce harmful emissions such as carbon monoxide, unburned hydrocarbons, and carcinogenic particulates. On the downside, ethanol combustion reacts with more nitrogen, which can marginally increase ozone-forming NO_X. Ethanol could also be blended with gasoline to reduce its sulfur content and SO_X emissions (which contribute to acid rain and cancer concerns).

Ethanol also behaves as a solvent and in high concentrations can cause corrosion of metal parts and deterioration of rubber and plastic, something that engine manufacturers must take that into account. The problem does not seem to arise at low concentrations though as engine modifications are not recommended for such blends (in the range of 2 to 10% v/v). European standards allow only for blends up to 5% v/v. Approximately 30% of all gasoline sold in US is 10% v/v ethanol blends (E10) and in Brazil 20–25% is made up of blends. Brazilian automakers produce vehicles with engine components that are resistant to ethanol in high concentrations, in addition to vehicles that run on even higher portions of ethanol fuel and ethanol only vehicles. Such flexible fuel vehicles (FFVs) are becoming increasingly popular in the United States (US) and the European Union (EU).

The separation of ethanol from gasoline can occur under certain conditions; in temperate climates water contamination can trigger phase separation. For refiners even adding small amounts of ethanol to gasoline will raise its vapor pressure, which can affect engine performance and result in increased emissions. To combat this one approach has been to combine ethanol with isobutylene to produce an additive ETBE (ethyl tertiary butyl ether). A typical 15% v/v blend of ETBE with gasoline has a biofuel content of 6.3% v/v (the isobutyl component is synthesized from petroleum thus reducing the ethanol's displacement of gasoline). ETBE and MTBE (methyl tertiary butyl ether) share many similarities. Both are toxic and possibly carcinogenic, ETBE is less water-soluble than MTBE and disperses less rapidly and is supposed to be easier to clean up. As ETBE does not raise the vapor pressure of gasoline, it blends more easily, is less complicated to transport and will not separate if exposed to water. Thus, it has attracted great interest especially amongst European refiners. US refiners choose to

modify the 'base' gasoline to have a lower vapor pressure to accommodate the ethanol, in addition during storage or transport 'splash blending' is used to avoid phase separation.

A few companies have developed additives to allow the blending of ethanol (5 to 15% v/v) and diesel. The additive package comprises a surfactant (stabilize the emulsion), lubricant (compensate for loss of lubricity) and a cetane enhancer (improves combustion efficiency), these E-diesel blends are likely to be limited to niche applications for fleet vehicles due to technical and safety constraints associated with the relatively high volatility of ethanol-diesel blends.

1.9.4 Lipid-Derived Biofuels

1.9.4.1 Vegetable Oil

Oilseed crops such as rapeseed, sunflower, soybean and palm have the potential to generate large quantities of oil that could be used as diesel substitutes. Restaurant waste oil (RWO) and animal fat from meat slaughterhouses are also potential feedstocks for the manufacture of diesel substitutes. After purification, this oil can burn directly in some internal combustion engines. Oils from seeds are usually extracted using chemical solvents (crushing processes have proven to be too energy intensive), the meal left over is often sold as animal fodder or used as fertilizer. Unused vegetable oil cannot be used directly in diesel engines primarily due to its high viscosity at cooler temperatures and as a result, the engines need to be refitted with heaters for the oil or they must be dedicated engines (Elsbett engine). Modern diesels (electronic timing, combustion control etc) are generally not compatible to run on unused vegetable oil.

Unused vegetable oil is difficult to blend with diesel because it tends to coagulate at lower temperatures. Each type of plant oil has unique properties that affect engine performance. Some tropical oils, such as coconut, have more saturated, shorter chained fatty acids and can be blended directly with diesel fuel, offering the potential for the use of blends of unused vegetable oil-diesel fuel in unmodified engines in tropical regions. In warm regions, where the oil does not thicken easily, unused vegetable oil can be a viable alternative as a diesel fuel substitute. In cooler climates, the technical challenges to keep the oil flowing limits its use. However, in Europe fuel quality standards have been developed for pure rapeseed oil and some limited use in daily operation is reported. For example, in Ireland some efforts are being made to evaluate low-level blends of certain pure vegetable oil types in existing vehicles.

1.9.4.2 Biodiesel

Biodiesel is produced by chemical combination of bio-oil with an alcohol (methanol or ethanol) in a process known as *transesterification* (NREL, 2009; Speight, 2008, 2011a). The resulting biodiesel is an alkyl ester of fatty acid, which contains an alcohol group attached to a single hydrocarbon chain comparable in length to that of diesel ($C_{10}H_{22}$ to $C_{15}H_{32}$) and when compared to unused vegetable oil it is a more blendable form. This reaction occurs by heating a mixture of 80 to 90% w/w oil, 10 to 20% w/w methanol and a catalyst (typically NaOH or KOH but acid catalysts are also used). Typical processes yield a volume of biodiesel equivalent to the volume of the biomass oil.

Methanol has been the most commonly used alcohol in the commercial production of biodiesel because it is the less expensive of the two. In addition, ethanol presents challenges in separating the glycerin by-product from the biodiesel and requires greater energy. Due to the wide variety of feedstock from which bio-oils are produced there is a greater range in the characteristics of biodiesel fuels (mix of molecules that varies somewhat depending upon the initial oil or fat source from which the fuel is synthesized). Some oils are more saturated which affects viscosity and the combustibility properties of the biodiesel.

In Europe rapeseed and sunflower are the dominant feedstock whereas in the US soybean is preferred (because of the vast production capability) and in tropical and sub-tropical countries, numerous plant oils such as palm oil, coconut oil and jatropha oil are some of the leading candidates. In the US, B20 blends have been used extensively, in Europe B5 blends are permitted and B2 blends have been used extensively in many countries.

Biodiesel contains 88 to 95% of the energy of diesel in addition it can also improve diesel lubricity and raise the cetane value making it a strong contender to diesel. The alcohol component of biodiesel contains oxygen, which helps to complete the combustion reducing harmful emissions (carbon monoxide, unburned hydrocarbons, and carcinogenic particulates). Like ethanol, biodiesel does not contain sulfur (no SO_X emissions). Biodiesel blends are sensitive to cold conditions and require anti-freeze precautions (similar to standard #2 diesel). Oxidation may occur if stored for too long, however, additives may be considered to prolong life. These loosen and dissolve sediments (it acts like a detergent) in tanks and attack rubber, these effects are minimal at low concentrations and at higher blends cold be avoided by paying attention to materials used in the fuel handling system (blends above 20% may require modest engine modifications, rubber hoses sensitive to solvent character of biodiesel) (National Biodiesel Board, 2007).

References

Badger, P.C. 2002. *Ethanol from Cellulose: A General Review. In: Trends in New Crops and New Uses*. J. Janick and A. Whipkey (Editors). ASHS Press, Alexandria, Virginia. Page 17–21

Balat, M. 2011. *Fuels from Biomass – Overview. In: The Biofuels Handbook*. James G. Speight (Editor). Royal Society of Chemistry, London, United Kingdom. Part 1, Chapter 3.

Bower, T. 2009. *Oil: Money, politics, and Power in the 21st Century*. Grand Central Publishing, New York.

Cherubini, F. 2010. *The Biorefinery Concept: Using Biomass Instead of Oil for Producing Energy and Chemicals*. Energy Conversion and Management, 51: 1412–1421.

Cherubini, F., and Ulgiati, S. 2010. *Crop Residues as Raw Materials for Biorefinery Systems – A LCA Case Study*. Applied Energy, 87: 47–57.

D1 Oils. 2006. *The Birth of a Global Biodiesel Business*. www.d1plc.com/about/history.php, accessed 15 May 2011.

Demirbaş, A. 2001. *Biomass Resource Facilities and Biomass Conversion Processing For Fuels And Chemicals*. Energy Convers Management, 42: 1357–1378.

Demirbaş, A. 2006. *Global Renewable Energy Resources*. Energy Sources Part A 28: 779–792.

Demirbaş, M.F. 2009. *Bio-refineries for Biofuel Upgrading: A Critical Review*. Applied Energy, 86: S151-S161.

Downing, M., Walsh, M., and McLaughlin, S. 1995. "Perennial Grasses for Energy and Conservation: Evaluating Some Ecological, Agricultural, and Economic Issues." Proceedings. Environmental Enhancement Through Agriculture. Center for Agriculture, Food and Environment, Tufts University, Medford, Massachusetts. November 15–17.

Ekman, A., and Borjesson, P. 2011. *Environmental Assessment of Propionic Acid Produced in an Agricultural Biomass-Based Biorefinery System*. Journal of Cleaner Production, 19: 1257–1265.

Ericsson, K., and Nilsson, L.J. 2006. *Assessment of the Potential Biomass Supply in Europe Using a Resource-Focused Approach*. Biomass and Bioenergy 30: 1–15.

FAOSTAT. 2012. Food and Agriculture Organization of the United Nations. http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor; accessed July 19, 2013.

Fitzpatrick, M., Champagne, P., Cunningham, M.F., and Whitney, R.A. 2010. *A Biorefinery Processing Perspective: Treatment of Lignocellulosic Materials for the Production of Value-Added Products*. Bioresource Technology, 101: 8915–8922.

Fulton, L., Howes, T. and Hardy, J. 2004. "Biofuels for Transport: An International Perspective." International Energy Agency. Paris, France.

Gary, J.G., Handwerk, G.E., and Kaiser, M.J. 2007. *Petroleum Refining: Technology and Economics*, 5th Edition. CRC Press, Taylor & Francis Group, Boca Raton, Florida.

Giampietro, M., and Mayumi, K. 2009. *The Biofuel Delusion – The Fallacy of Large-Scale Agro-fuel Production*. Earthscan, London, United Kingdom.

Gnansounou, E., Bedniaguine, D., and Dauriat, A. 2005. "Promoting Bioethanol Production Through Clean Development Mechanism: Findings and Lessons Learned from the ASIATIC Project." Proceedings. 7th IAEE European Energy Conference, Bergen, Norway. August 28–30.

Hamelinck, C.N. and Faaij, A.P.C. 2006. *Outlook for Advanced Biofuels*. Energy Policy, 34(17): 3268–3283.

Hernandez, R. 2011. *Petroleum Displacement Potential of Next Generation Biofuels and Approaching Commercialization*. Current Opinions in Chemical Engineering, 1: 43–46.

Hoogwijk, M., Faaij, A., Eickhout, B., de Vries, B., and Turkenburg, W. 2005. *Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios*. Biomass and Bioenergy 29: 225–257.

Hsu, C.S., and Robinson, P.R. (Editors) 2006. *Practical Advances in Petroleum Processing Volume 1 and Volume 2*. Springer Science, New York.

Huang, H.J., Ramaswamy, S., Al-Dajani, W.W., and Tschirner, U. 2010. *Process Modeling and Analysis of Pulp Mill-Based Integrated Biorefinery with Hemicellulose Pre-Extraction for Ethanol Production: A Comparative Study*. Bioresource Technology, 101: 624–631.

IFP. 2012. *Biofuels Update: Growth in National and International Markets*. Panorama 2012. IFP Energies Nouvelles, Rueil-Malmaison Cedex Paris, France

Kaltner, F., Azevedo, G.F.P., Campos, I.A., and Mundim, A.O.F. 2005. "Biofuels for Transportation: Brazilian Potential and Implication for Sustainable Agriculture and Energy in the 21st Century." Prepared for the Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Rio de Janeiro, Brazil. November. Page 23.

Kaparaju, P., Serrano, M., Thomsen, A.B., Kongjan, P., and Angelidaki, I. 2009. *Bioethanol, Bio-hydrogen and Biogas Production from Wheat Straw in a Biorefinery Concept*. Bioresource Technology. 100: 2562–2568.

Lee, S., Speight, J.G., and Loyalka, S.K. 2007. *Handbook of Alternative Fuel Technologies*, CRC Press, Taylor and Francis Group, Boca Raton, Florida.

Lee, S., and Shah, Y.T. 2013. *Biofuels and Bioenergy: Processes and Technologies*. CRC Press, Taylor & Francis Group, Boca Raton, Florida.

Liu, S., Abrahamson, L.P., and Scott, G.M. 2012. *Biorefinery: Ensuring Biomass as a Sustainable Renewable Source of Chemicals, Materials, and Energy*. Biomass and Bioenergy, 36: 1–4.

Luo, G., Talebnia, F., Karakshev, D., Xie, L., Zhou, Q., and Angelidaki, I. 2011. *Enhanced Bioenergy Recovery from Rapeseed Plant in a Biorefinery Concept*. Bioresource Technology, 102: 1433–1439.

Mandal, R. 2005. The Indian Biofuels Program – National Mission on Bio-Diesel. Presentation to the International Conference and Expo, Biofuels 2012: Vision to Reality, New Delhi, 17–18 October

National Biodiesel Board. 2007. www.biodiesel.org/pdf_files/fuelfactsheets/prod_quality.pdf

Nersesian, R.L. 2010. Energy for the 21st Century – *A Comprehensive Guide to Conventional and Alternative Energy Sources* 2nd Edition. M.E. Sharpe. Armonk, New York.

NREL. 2009. "Biodiesel Handling and Use Guide 4th Edition." Report No. NREL/TP-540–43672 Revised January 2009. National Renewable Energy Laboratory, Golden, Colorado.

NREL 2011. Thermochemical Conversion Technologies – Projects. US National Renewable Energy Laboratory).www.nrel.gov/biomass/proj_thermochemical_conversion.html, accessed 20 May 2011

Pandey, S., Sharma, A., and Sahoo, P.K. 2012. *Experimental Investigation on the Performance and Emission Characteristics of a Diesel Engine Fueled with Ethanol, Diesel and Jatropha Based Biodiesel Blends*. International Journal of Advances in Engineering & Technology, 4(2): pp. 341–353.

RFA 2005. "Homegrown for the Homeland: Ethanol Industry Outlook 2005." Renewable Fuels Association, Washington, DC. www.ethanolrfa.org/objects/pdf/outlook/outlook_2005.pdf accessed 18 April 2011.

Rosenberg, J.N., Mathias, A., Korth, K., Betenbaugh, M.J., and Oyler, G.A. 2011. *Micro-algal Biomass Production and Carbon Dioxide Sequestration from an Integrated Ethanol Biorefinery in Iowa: A Technical Appraisal and Economic Feasibility Evaluation.* Biomass and Bioenergy, 35: 3865–3876.

Seifried, D., and Witzel, W. *Renewable Energy – the Facts.* Earthscan, London, United Kingdom.

Singh, A., Nigam, P.S., and Murphy, J.D. 2011. *Mechanism and Challenges in Commercialization of Algal Biofuels*. Bioresource Technology, 102: 26–34.

Singh, A., and Olsen, S.I. 2011. *A Critical Review of Biochemical Conversion, Sustainability and Life Cycle Assessment of Algal Biofuels*. Applied Energy, 88: 3548–3555.

Soares Pinto, M. 2011. "Global Biofuels Outlook 2010–2020." Proceedings. World Biofuels Markets, Rotterdam. March 23.

Speight, J.G., and Ozum, B. 2002. Petroleum Refining Processes. Marcel Dekker Inc., New York.

Speight, J.G. 2008. *Synthetic Fuels Handbook: Properties, Processes, and Performance*. McGraw-Hill, New York.

Speight, J.G. (Editor). 2011a. *The Biofuels Handbook*. Royal Society of Chemistry, London, United Kingdom.

Speight, J.G. 2011b. *The Refinery of the Future*. Gulf Professional Publishing, Elsevier, Oxford, United Kingdom.

Speight, J.G. 2013a. *The Chemistry and Technology of Coal 3rd Edition*. CRC Press, Taylor & Francis Group, Boca Raton, Florida.

Speight, J.G. 2013b. *Coal-Fired Power Generation Handbook*. Scrivener Publishing, Salem, Massachusetts, 2013.

Speight, J.G. 2014. *The Chemistry and Technology of Petroleum.* 5th Edition. CRC Press, Taylor and Francis Group, Boca Raton, Florida.

Tampier, M., Smith, D., Bibeau, E., and Beauchemin,, P.A. 2005. "Identifying Environmentally Preferable Uses for Biomass Resources." Stage 2 Report: Life-Cycle GHG Emission Reduction Benefits of Selected Feedstock-to-Product Threads. Updated Version. Envirochem Services Inc., North Vancouver, British Columbia, Canada. January 21.

Thorsell, S., Epplin, F.M., Huhnke, R.L., and Taliaferro, C.M. 2004. *Economics of Coordinated Biorefinery Feedstock Harvest System: Lignocellulosic Biomass Harvest Cost.* Biomass and Bioenergy, 27: 327–337.

Uihlein, A., and Schebek, L. 2009. *Environmental Impacts of Lignocellulose Feedstock Biorefinery System: An Assessment. Biomass and Bioenergy*, 33: 793–802.

UNCTAD. 2008. "Biofuel Production Technologies: Status, Prospects and Implications for Trade and Development." Report No. UNCTAD/DITC/TED/2007/10. United Nations Conference on Trade and Development, Geneva, Switzerland.

2

Environmental Aspects

2.1 Introduction

The use of biofuels is not as environmentally acceptable as some proponents would have the scientific community and the general public believe. In fact, there are various social, economic, environmental and technical issues with biofuel production. These include (1) the effect of moderating oil prices, (2) the *food vs fuel* debate, (3) poverty reduction potential, (4) carbon emissions levels, (5) sustainable biofuel production, (6) deforestation and soil erosion, (7) loss of biodiversity, (8) impact on water resources, (9) the possible modifications necessary to convert a gasoline/diesel engine to a biofuel engine, as well as (10) energy balance and efficiency. A major issue is that not all biofuels perform equally in terms of their impact on climate, energy security and ecosystems and this suggests that environmental and social impacts need to be assessed throughout the entire life cycle. A persistent and collaborative effort to maintain 1st generation biofuels as 'green' will require a rethink of legislation, monitoring and enforcement practices in some producer countries where such weaknesses have caused and continue to cause large scale destruction of habitats

(carbon sinks of global importance). The argument could even be made by poorer biofuel producing countries that wealthy importing nations should be made to pay a premium for biofuels which have minimal environmental and social impact as part of their social responsibility.

The food-vs-fuel debate is particularly relevant and focuses on the issue of using land and resources to produce biofuels or food and the risk of diverting farmland or crops for biofuels production in detriment of the food supply on a global scale. The debate refers to the possibility that by farmers increasing their production of these crops, often through government subsidy incentives, their time and land is shifted away from other types of non-biofuel crops driving up the price of non-biofuel crops due to the decrease in production. Therefore, it is not only that there is an increase in demand for the food staples, like corn and cassava, that sustain the majority of the poor population of the world, but this also has the potential to increase the price of the remaining crops that these individuals would otherwise need to utilize to supplement their diets.

There is also the dispute that the expansion of farming for biofuel production causes unacceptable loss of biodiversity for a much less significant decrease in fossil fuel consumption (Cook et al., 1991; Campbell and Doswald, 2009; Davis et al., 2010). The loss of biodiversity also makes heavy dependence on biofuels very risky by reducing the ability to deal with blights affecting the few important biofuel crops. Food crops have recovered from blights when the old stock was mixed with blight resistant wild strains, but as biodiversity is lost to excessive agriculture, the possibilities for recovering from blights are lost.

The production of biofuels from raw materials requires energy (for farming, transport and conversion to final product and the production/application of fertilizers, pesticides, herbicides and fungicides) and has environmental consequences.

The energy balance of a biofuel (*net energy gain*) is determined by the amount of energy put into the manufacture of fuel compared to the amount of energy released when it is burned in a vehicle. This varies by feedstock and feedstock distribution (Wright, 1994) according to the assumptions used. Biodiesel made from sunflower may produce only 0.46 times the input rate of fuel energy (Pimentel and Patzek, 2005). Biodiesel made from soybeans may produce 3.2 times the input rate of fossil fuels, which compares to 0.805 for gasoline and 0.843 for diesel made from petroleum (Sheehan et al., 1998). Biofuels may require higher energy input per unit of Btu energy content produced than fossil fuels – petroleum can be pumped out of the ground and processed more efficiently than biofuels can be grown and processed. However, this is not necessarily a reason to

use oil instead of biofuels, nor does it have an impact on the environmental benefits provided by a given biofuel.

Life cycle assessments of biofuel production show that under certain circumstances, biofuels produce only limited savings (if any savings at all) in energy and greenhouse gas emissions (Fargione et al., 2008; Searchinger et al., 2008). Fertilizer inputs and the transportation of biomass across large distances can reduce any greenhouse gas savings achieved. The location of biofuel processing plants can be planned to minimize the need for transport and agricultural regimes can be developed to limit the amount of fertilizer used for biomass production.

Biofuels and other forms of renewable energy aim to be carbon neutral or even carbon negative. Carbon neutral means that the carbon released during the use of the fuel, such as through burning to power transport or generate electricity, is reabsorbed and balanced by the carbon absorbed by new plant growth. These plants are then harvested to make the next batch of fuel. Carbon neutral fuels lead to no net increases in human contributions to atmospheric carbon dioxide levels, reducing the human contributions to global climate change.

Concerns about climate change add a most complex challenge to the long-term use of fossil fuels in a sustainable development context. In disregarding the great underlying uncertainties of future climate, emissions and the efficacy of response options, climate change is commonly presented simply as an environmental issue requiring urgent intervention. Further improvement in the environmental performance of coal will not only be required but will be a necessity. While improved fossil fuel conversion technologies (Speight, 2013, 2014) have provided very substantial efficiency and emission improvements to date, accelerated technological effort is required to reduce greenhouse gas emissions (Davis et al., 2010). Deployment of cleaner and higher efficiency technologies will be important in both developed and developing countries. Climate change considerations must always be considered. Any response must be affordable and provide the basis for sustainable development, by addressing ongoing economic and social requirements as well as the environmental challenge.

Indeed, energy production from fossil fuels and use of the products can be major sources of environmental impacts, which in turn can threaten the overall social and economic development and objectives that fossil fuel use is expected to promote. At regional and global levels, fossil fuel consumption leads to acid rain and most likely to global climate change (aka global warming or *climatism*), which is an emotional issue, partly because of the truths and myths that have been circulated about global climate change (Bell, 2011; Goreham, 2013). Indeed, the Earth is currently in an

inter-glacial period which, it should not be forgotten, is included in the overall warming.

Before emotions run wild, it must be recognized that the contribution of the interglacial warming to the overall warming of the Earth is unknown just as the contribution of greenhouse gases (and global climate change) from anthropogenic sources to the warming trend is also unknown. Nevertheless, the production of energy from fossil fuels is one of the greatest concerns of the countries in 21st century. By the same token, the contribution of the use of biofuels must also be monitored and mathematical manipulation to show that biofuels have a zero contribution to global climate change is not valid.

The aim of monitoring any form of fuel use is to achieve a carbon negative contribution to the environment. In the case of biofuels, this is achieved when a portion of the biomass is used for carbon sequestration. Calculating exactly how much greenhouse gas is produced in burning biofuels is a complex and inexact process, which depends very much on the method by which the fuel is produced and other assumptions made in the calculation. Researchers need to address measurement, modeling and validation of greenhouse gases for different biofuel feedstock especially the new energy crops such as switch grass, poplar and other dedicated perennials.

The carbon emissions (*carbon footprint*) produced by biofuels are calculated using a *life cycle analysis* (LCA) which is a *cradle-to-grave* or *well-to-wheels* approach to calculate the total amount of carbon dioxide and other greenhouse gases emitted during biofuel production, from putting seeds in the ground to using the fuel in cars and trucks which can also effect global trade (Meyer et al., 2013). Many different life cycle analyses have been performed for different biofuels, with widely differing results. Several *well-to-wheel* analyses for biofuels have shown that first generation biofuels can reduce carbon emissions, with savings depending on the feedstock used and second generation biofuels can produce even higher savings when compared to using fossil fuels. However, those studies typically do not take into account emissions from nitrogen fixation, or additional carbon emissions due to indirect land use changes.

The increased manufacture of biofuels will require increasing land areas to be used for agriculture. Second and third generation biofuel processes can ease the pressure on land because they can use waste biomass and existing (untapped) sources of biomass such as crop residues and potentially even marine algae.

In some regions of the world, a combination of increasing demand for food and increasing demand for biofuel, are causing deforestation and threats to biodiversity. There is a pressing need for sustainable palm oil

production for the food and fuel industries; palm oil is used in a wide variety of food products. Significant areas are likely to be dedicated to sugarcane in future years as demand for ethanol increases worldwide. The expansion of sugarcane plantations will place pressure on environmentally sensitive native ecosystems including rainforest and grasslands in South America. In forest ecosystems, these effects themselves will undermine the climate benefits of alternative fuels in addition to representing a major threat to global biodiversity. Although biofuels are generally considered to improve net carbon output, biodiesel and other fuels do produce local air pollution, including nitrogen oxides, the principal cause of smog.

Nevertheless, increasing energy use, climate change and carbon dioxide emissions from fossil fuels make switching to low-carbon fuels a high priority (Fargione et al., 2008). Biofuels are a potential low-carbon energy source, but whether biofuels offer carbon savings depends on how they are produced. Converting rainforests, peat lands, savannas, or grasslands to produce food crop-based biofuels in Brazil, Southeast Asia and the United States creates a *biofuel carbon debt* by releasing 17 to 420 times more carbon dioxide than the annual greenhouse gas (greenhouse gas) reductions that these biofuels would provide by displacing fossil fuels. In contrast, biofuels made from waste biomass or from biomass grown on degraded and abandoned agricultural lands planted with perennials incur little or no carbon debt and can offer immediate and sustained greenhouse gas advantages (Fargione et al., 2008).

This chapter presents the environmental risks associated with growing biomass for fuel production such as loss of wild habitat, loss of biodiversity, negative impacts on soil, air and water and makes the case for carefully managing biofuel production processes to minimize ecological impact. New energy crops and improved management practices (methods of cultivation and harvest) that offer environmental improvements are introduced. Alternative farming methods that can reduce soil erosion, improve soil quality, reduce water consumption, reduce susceptibility to pests and diseases (minimize usage of herbicides and pesticides) are also introduced. Ultimately, the choice of biofuel may be largely subjective as decision makers weigh the merits and drawbacks related to different desired environmental ends and this chapter aims to familiarize the reader with the relevant parameters.

2.2 Greenhouse Gas Emissions

There are several gases that are known as *greenhouse gases*. The three main greenhouse gases that are products of fossil fuel refining and use

are (1) carbon dioxide, (2) nitrous oxide and (3) methane (Fogg and Sangster, 2003; David et al., 2010). Carbon dioxide is the main contributor to climate change. Methane is generally not as abundant as carbon dioxide but is produced during refining and, if emitted into the atmosphere is a powerful greenhouse gas and more effective at trapping heat. However, gaseous emissions associated with petroleum refining are more extensive that carbon dioxide and methane and typically include process gases, petrochemical gases, volatile organic compounds (VOCs), carbon monoxide (CO), sulfur oxides (SO_x), nitrogen oxides (NO_x), particulates, ammonia (NH_3) and hydrogen sulfide (H_2S). These effluents may be discharged as air emissions and must be treated. However, gaseous emissions are more difficult to capture than wastewater or solid waste and, thus, are the largest source of untreated wastes released to the environment.

Greenhouse gases trap heat and make the planet warmer. Human activities are responsible for almost all of the increase in greenhouse gases in the atmosphere over the last 150 years. The largest source of greenhouse gas emissions from human activities in the United States is from burning fossil fuels for electricity, heat and transportation. The US EPA tracks total U.S. emissions by publishing annually the Inventory of US Greenhouse Gases and Sinks (US EPA. 2013), which contains *estimates* the total national greenhouse gas emissions and removals associated with human activities across the United States.

The primary sources of greenhouse gas emissions in the United States are: (1) electricity production from fossil fuels, which generates the largest share of greenhouse gas emissions, (2) transportation, primarily from burning fossil fuel for automobiles, trucks, ships, trains and planes, (3) industry, primarily from burning fossil fuels for energy as well as greenhouse gas emissions from certain chemical reactions necessary to produce goods from raw materials, (4) commercial and residential sources, primarily from fossil fuels burned for heat, the use of certain products that contain greenhouse gases and the handling of waste and (5) agriculture, which come from livestock such as cows, agricultural soils and rice production. On the other hand, land use and forestry offset (typically less than 15%) greenhouse gas emissions from other sources by acting as a sink (absorbing carbon dioxide from the atmosphere) or a source of greenhouse gas emissions. It has been estimated that in the United States, since 1990, managed forests and other lands have absorbed more carbon dioxide from the atmosphere than they emit.

Thus, one of the key drivers for the development of biofuels is concern about global climate change caused by the burning of fossil fuels and greenhouse gas (greenhouse gas) emissions. Scientific evidence points

to the fact that the Earth is warming at an accelerated rate and production and use of transportation fuels contribute for about 25% of the global energy related greenhouse gas emissions and that share is rising (Baumert, Herzog, Pershing, 2005). In the US, transport accounts for 27% of total emissions (42% of carbon dioxide emissions) and in the EU 28% of total emissions (Fulton et al., 2004). In rapidly industrializing countries such as China and India, which now lead global growth in vehicle sales, emissions from the transport sector will surely rise far more rapidly over the next decade. Biofuels provide an option for dramatically reducing demand for oil and transport related greenhouse gas emissions.

Some governments are expected to bring pressure even to the shipping industry to reduce its global warming impact by diversifying fuel choices away from highly polluting heavy fuel oil (HFO), marine gas oil (MGO) and diesel. Given the environmental implications, special consideration could be given to biofuels (liquid and gaseous) to reduce greenhouse gas emissions from marine transport. A large scale switch to biofuels is not possible in the near future (although biofuels may be able to use some of the existing liquid fuelling infrastructure nothing currently exists for gaseous biofuels), but will probably prove viable in niche applications in regions where biofuels are available. Different blends could be considered given availability and price.

2.3 Life Cycle Considerations of Biofuels

Environmental concerns, along with the goals of energy diversification and rural development accompanied by policies, drive the use of liquid biofuels for transport in several countries, notably in Europe. Since they started these policies, the perception of the environmental benefits of biofuels has changed significantly. At present there is controversy regarding the benefits and possible negative consequences in terms of environmental impact. The negative consequences of biofuels development are (1) the occupation of natural areas to expand cultivation and (2) energy efficiency in addition to the possible influence on food prices. The latter reinforces the transformation of natural areas to agricultural land.

For petroleum products (gasoline and diesel) a life cycle analysis (climate, processing, transport) of the climate impact includes all greenhouse gas emissions associated with exploration, production, transport, refining, storage, distribution, retail, fuelling, evaporative and exhaust emissions. For biofuels the life cycle stages considered are planting, harvesting, impact on soil carbon storage, emissions associated with energy required for farm

and irrigation machinery, production and use of fertilizers, pesticides and herbicides, processing of feedstock into biofuel and co-products, transportation of feedstock and the final fuel, storing, distributing, retailing and the impacts of fuelling and evaporative and exhaust emissions from combustion (Kojima, Johnson, 2005).

Furthermore, newer studies also include land use changes, as this can lead to higher levels of accuracy in accounting of greenhouse gas emissions in life cycle analyses (Davis et al., 2009; Haberl, et al., 2012). The climate impact of biofuels depends upon the fossil energy balance (how much energy is contained in the biofuel versus how much fossil fuel energy was required to produce them and depends on the intensity of farming systems, chemical inputs, processing, transportation and the final product). Unlike carbon containing fossil fuels stored for millions of years within the Earth's crust, biofuels are produced from bio-organics (plant and animal origin) over the last ten years and have the potential to be 'carbon neutral' as they form part of the natural fixed carbon cycle (emitting only as much CO_2 through combustion as the feedstock absorbed through photosynthesis).

Outside of combustion, greenhouse gases are also produced during the production, cultivation, manufacture of nitrogenous fertilizers, consumption of diesel in farm equipment and refining. Biofuel production also produces co-products that can be substituted for fossil fuel inputs during its life cycle. With the exception of a few scientific studies that point to increases in greenhouse gases from biofuels most literature reports a significant reduction in greenhouse gases from both ethanol and biodiesel compared to diesel and gasoline. Scientists agree that biofuels produced using current technologies (Chapter 1) can result in significant reductions with even more dramatic results as new conversion technologies becomes main stream.

However the issues are not clear cut and figures vary widely based on the perspective of the author when it comes to assumptions about feedstock usage, land use changes (where and how much additional land will be required and if it will displace wild ecosystems), crop production techniques (fertilizers, pesticides, tilling of soil, farm management practices), crop yields, processing and refining efficiencies, efficiencies of ethanol and gasoline, diesel and biodiesel, including blends, credits attributed to co-products and the methodologies for calculating total life cycle emissions (Davis et al., 2009).

To add to the complexity of quantifying greenhouse gas emissions: carbon dioxide, nitrous oxide, methane, hydrogen, ozone and particulate matter – not a direct result of combustion, photochemical reactions involving nitrogen oxides, carbon monoxide and non-methane organic compounds

(NMOCs) and their impact is now considered to some extent in calculating the life-cycle greenhouse gas balance of these fuels.

The reference point for evaluating greenhouse gas balances is petrofuels and they are rarely ever evaluated with full greenhouse gas accounting from well-to-wheel. A strong case could be had for biofuels if waste streams (such as agricultural waste, forestry waste, farm waste, crop waste and municipal solid waste) were used as feedstock (Chapter 1). However these cellulosic conversion technologies have not yet been fully commercialized (pilot and demonstration plants to test feasibility of these technologies) but it is generally assumed that greenhouse gas emissions will be lower.

2.3.1 Feedstock Production, Harvest, Processing, Transport

Moreover, feedstock production, harvest, processing and transport are logistical issues, which involve planning, implementing and controlling the efficient, effective flow and storage of biomass feedstocks between supply and use. Without assurance of efficient feedstock flow from point of origin to point of use, biofuel production can be limited by capacity and cost-prohibitive factors. Four major unit processes contribute to a successful and sustainable biomass feedstock logistics system: (1) harvest and collection, (2) storage, (3) preprocessing and (4) transportation.

Harvest and collection operations involve acquiring biomass from the point of origin and moving it to a storage or queuing location. Examples include cutting, harvesting, collecting, hauling and often some form of densification such as baling. *Storage* operations are essential for holding biomass material in a stable form until preprocessing or transport to the biorefinery. Storage could be at locations near the harvesting areas, at the biorefinery, or both. *Preprocessing* involves processes that physically, chemically, or biologically transform biomass into a state more suitable for transport or conversion to liquid fuels. Examples include increasing the density (e.g., pellets or torrefied material), on-site pyrolysis, grinding, drying, chemically treating, ensiling, fractionating and blending. Finally, transportation is the movement of biomass through the logistics system from harvest and collection to the biorefinery. Biomass transport options are typically constrained to any existing transportation infrastructure such as truck, rail, barge, or pipeline.

As outlined above, the change in land use and use of fertilizers is generally the most profound greenhouse gas stage in the biofuel lifecycle and the gases released (carbon dioxide, nitrous oxide and methane) from crop production normally come from the decomposition of biodegradable organic

fraction in soil and inorganic fertilizers. For example, when biodiesel is produced from rapeseed, sunflower and soybeans, the step that had the greatest impact on greenhouse gases in a life cycle assessment was production (including fertiliser, land, water and mechanised labour) (Davis et al., 2009; Sanz Requena, et al., 2011). Various crops release greenhouse gases or sequester (capture and store) carbon at different rates depending upon fertilizer requirements, root systems, climate, solar resources and soil productivity (impact crop yields and fertilizer application rates).

Refining, transport and combustion of biofuels impacts negatively water and air quality. The environmental impact of land-use change, crop management and selection, harvesting, processing and transport of biofuels will be more profound as biofuel production ramps up to meet demand. This will result in more sustainable crop management practices and it will accelerate the introduction of new technologies for environmental preservation.

2.3.1.1 Land Use

Although biofuels can in principle be produced from any organic source, most of the current or first generation biofuels are based on food crops and the majority (approximately 98%) of current biofuel production involves the production of ethanol from sugars and biodiesel from oil seeds (Msangi *et al.,* 2008). The main crops used in ethanol production are sugarcane and maize, with oil palm and rapeseed most often used to produce biodiesel. Different feedstocks are more or less efficient in the production of bioenergy (Sheil *et al.,* 2009) and some feedstocks also provide useful co-products such as oilcake as animal feed. In general, for the first generation biofuels, the type of feedstock used is pivotal because of the wide variety used.

Biofuel targets have largely been set as part of renewable energy policies in the context of climate change mitigation. Biofuels can undoubtedly contribute to climate change mitigation when grown in appropriate areas. For example, recent studies have suggested that when sugarcane is used to produce ethanol, 80 to 100% greenhouse gas savings could be achieved and that oilseed production for biodiesel can similarly achieve emissions savings of 20 to 85% (Howarth *et al.,* 2009). When biofuels achieve real emissions reductions biodiversity benefits also through climate change impact reduction. This is an important trade-off to keep in mind when considering some of the potential negative impacts on biodiversity resulting from the cultivation of feedstocks for biofuels production.

Moreover, the time frame over which the impacts on biodiversity resulting from biofuel production are examined also needs to be considered.

Indeed, it has been suggested (Eickhout *et al.,* 2008) that in the short-to medium-term, where biofuel production replaces natural ecosystems, including those with lower carbon storage values, the negative effects of land use change on biodiversity are likely to outweigh any benefits that may be gained from climate change mitigation. Biofuels may further aid climate change mitigation with the development of more efficient biomass-use technologies such as generating energy through the combustion of bagasse (Machado-Filho, 2008).

However, the future of biofuels lies heavily in the environment, as defined by land use. Space and soil are needed for native plants and wildlife, as well as for crops used for food, feed, fiber, wood products and biofuel (liquid fuel derived from plant material) (Campbell and Doswald, 2009; Fargione et al., 2009). People also use land for homes, schools, jobs, transportation, mining and recreation. Social and economic forces influence the allocation of land to various uses. The recent increase in biofuel production offers the opportunity to design ways to select locations and management plans that are best suited to meet human needs while also protecting natural biodiversity (the variation of life within an ecosystem) (Dale et al., 2010).

Many aspects of biofuels have been closely studied. Analyses have been conducted on the environmental implications of the production of some biofuel feedstocks (the plant materials used to make biofuels) and on the logistics of their harvest, handling, storage, pretreatment and transportation from field to refinery (Dale et al., 2010). The integrated environmental and socioeconomic consequences associated with the increased use of bioenergy crops, make it critical to develop a landscape approach that takes into account changes in land use and management for bioenergy feedstocks that alter existing ecological properties. Such an approach can clarify the tradeoffs involved in making choices about land use for food production, bioenergy crops, biodiversity protection and other societal needs.

Considerable attention has been given to annual crops from which biofuel can be produced, including soybeans and corn. However, other feedstock options are based on stems, stalks, or woody components of plants, so-called ligno-cellulosic materials. Perennial crops, which do not need to be replanted after each harvest, such as grass species and fast-growing trees are typical of such feedstocks. These energy crops offer some environmental advantages compared to traditional annual crops, but they may demand innovative management techniques in order to be sustainable.

The organic matter in soil contains more than twice the carbon in atmospheric carbon dioxide and additional carbon is stored in biomass; because these pools of carbon are so large even small changes in their sizes can be of global significance (Powlson et al., 2005). The amount of

carbon stored in plants, debris and soils change as land use is altered, including when biomass is grown and harvested, scientific study is required to ascertain the impact of large scale carbon release from the soil and existing biomass as greater land area comes under cultivation of biomass, the gains made from biofuel usage could be cancelled out by carbon releases (leakage effects and gains made in one area are lost in another). These changes could extend over a long period of time before reaching a new equilibrium (studies being time dependent).

Burning associated with the clearing of rainforests in Indonesia and Malaysia to facilitate palm oil plantations was one of the largest contributors to greenhouse gas emissions in 1997 (Clay, 2004). The wide scale destruction and devastation of vast forestlands significantly impacted climate at both a regional and global scale, hydrological cycles were disrupted reducing precipitation and increasing temperatures. The destruction of the Amazon rainforest is a case in point where the disruption of the hydrological cycle could threaten to reduce rainfall to Brazil's *cerrado*, a vast expanse across the high plains home to some 935 species of bird and nearly 300 mammal species, many of them threatened and endangered (Rohter, 2005). The sustainable production and conversion of plants and plant residues into fuels present an opportunity to reduce the stress on forests and woodlands, wetlands, watersheds and upland ecosystems (Rosillo - Calle et al., 2008).

Converting land from natural cover to intensive agriculture (annual crops) reduces the plant biomass above ground and over time emits carbon from the soil (the reverse of a greenhouse gas benefit). Additionally, leaf rot declines and soil temperature and aeration increases. The same is true if natural forests are destroyed to facilitate the growing of 'sustainable' energy crops for biofuel production. The logical approach will be to convert land from intensive agriculture to perennial herbaceous species (grasses) and woody crops to improve soil carbon. Perennial crops deposit more carbon in the soil as roots and in the absence of tillage decomposition of soil matter slows (cultivation of perennials on land previously used for annual crops will increase the organic carbon content of the soil). Soils have the potential to store more carbon than the temporary CO_2 bond of biomass crops.

The potential to sequester additional carbon is site specific and depends on former and current land use, agricultural practices and climate and soil characteristics (Larson 2005). The maximum amount of carbon that could be stored in vegetation and soils is specific for given climatic conditions; in addition, carbon sequestration is reversible. Any carbon that accumulates in the soil or in plants could be released if the use or management of

land is converted back to previous uses such as intensive cropping (carbon storage in soils is only a short-term measure for reducing greenhouse gas emissions). The Indian government's ambitious plan proposes to utilize large tracts of wasteland which have been lying almost barren for decades (approx. 13.4 million hectares of waste land identified for jatropha biofuel plantations using wasteland afforestation).

Wasteland afforestation has been found to be a financially viable and environmentally sound method. In addition, wasteland tree planting is emerging as a potent tool for arresting the increased misuse and overexploitation of these lands and the associated environmental degradation. However, other studies have indicated that using marginal lands to grow energy crops may lead to unfeasible chains due to negative traits such as water not being easily accessible, poor organic matter in soil, long distances from transportation routes, excess sloping and pollution in the soil from previous use (Fahd, et al., 2011). The inclusion of leguminous crops/trees on poor soils can also result in a marked improvement in soil fertility. This can be achieved by increasing the amount of organic matter in soil through the addition of leaf litter and plant debris, efficient nutrient cycling, efficient biological nitrogen fixation, little loss of nutrients from the system, little erosion runoff and additional nutrient economy i.e. uptake from deeper layers and deposition on surface layer via litter.

2.3.1.2 Crop Management

Crop management involves a wide range of activities ranging from fertilizer and pesticide use to fuels used in farm and irrigation machinery and soil treatment. These all play a part in determining the impact of biofuels on climate. The use of farm and irrigation equipment releases CO_2, NO_X and hydrocarbons which help to create ozone. In the US and Europe high levels of irrigation are required for corn/soybean and rapeseed and in Brazil sugar cultivation in the northeast also requires irrigation. Seed cultivation requires a share of all the energy inputs during a previous crop cycle. The most significant factor in terms of climate impact is chemical fertilizer, which requires large amounts of fossil energy input. Some of the nitrogenous fertilizers used on fields are emitted as N_2O which is released directly from the soil or through run-off water.

It is estimated that 0.5–5.0% of N_2O in fertilizer volatilizes, furthermore, N_2O accounts for 6% of anthropogenic greenhouse gas emissions, nitrogenous fertilizers contributing 60% of this value (Silva Lora, et al., 2011). Atmospheric concentrations of N_2O are increasing at a rate of 0.2–0.3%

per annum. For example, in the US, large amounts of fertilizers are consumed in corn farming (~70% of the energy input), soybeans which are leguminous nitrogen fixers require less fertilizer. Efforts to reduce the use of fertilizers, pesticides and fossil fuel for powering machinery in addition to intercropping (soybean with perennials), the use of biofuels, the planting of perennial crops and conservation tilling (direct seeding), could significantly reduce greenhouse gas emissions and climate impact.

2.3.1.3 Feedstock Selection

In growing biomass for fuel, consideration must be given to (1) energy yield per hectare (2) fertilizer usage (3) soil carbon retention and (4) competition for food. Grains such as corn, barley and wheat grown in temperate climates are less efficient in land use and fertilizer when compared to sugarcane and palm oil trees grown in Brazil, Malaysia and Indonesia (Chapter 1). For example, palm oil trees produce 5x more oil per hectare than European rapeseed (1200 liters/hectare) and are thirteen times more productive than soybeans. Jatropha, while less productive than palm oil trees, is more productive per hectare than rapeseed. In the US, test plots of switchgrass have yielded about 10,900 liters of ethanol per year (ORNL, undated). Miscanthus and hybrid poplars also have potential for high yields (Science Daily, 2005).

In addition to their high yields per unit of land, energy crops have the distinct advantage of requiring less fertilizer and pesticide, do not require tilling and can sequester significant amounts of carbon in the soil and can improve the organic carbon content of degraded soils. For example, switchgrass expands its root system when harvested and increases the organic matter in soils and carbon sequestration.

Furthermore, switchgrass can be grown on land considered unsuitable for row crop production, including land that is subject to erosion and therefore unsuitable for corn production, as well as sandy and gravel-type soil in humid regions that typically produce low yields of other farm crops. No single method of establishing switchgrass can be suggested for all situations. The crop can be established by no-till and by conventional tillage. When seeded as part of a diverse mixture, planting guidelines for warm-season grass mixtures for conservation plantings should be followed. Regional guidelines for growing and managing switchgrass for bioenergy or conservation plantings are available. Several key factors can increase the likelihood of success for establishing switchgrass and also have an effect on switchgrass establishment and management as part of the life cycle assessment of the crop. These include, (1) planting switchgrass after the soil is

well warmed during the spring, (2) using seeds that have high germination potential, (3) providing no form of fertilization at the time of planting to minimize competition and (4) controlling weeds with chemical and/or cultural control methods.

The life cycle greenhouse gas impact depends on what the crops are replacing and if they are replacing wild ecosystems (savannahs, forests *etc.*), greenhouse gas emissions will probably increase, however, if energy crops are planted on wasteland (unproductive, arid) or are replacing annual crops, they have the potential to reduce emissions (jatropha and pongamia can thrive on wasteland). Crop and forest residues, animal wastes and the organic constituents of municipal solid waste could be used to produce fuel with next generation technologies. These feedstocks do not in themselves require land, chemicals or irrigation and can provide energy.

2.3.1.4 Harvesting

The procedure, timing and machinery used for harvesting affect the level of greenhouse gas emissions. On some soils, the removal of crop residue can result in the release of soil carbon (detrimental impact on the health of soil). Residual removal impacts physical, chemical and biological processes in the soil and can cause fluctuations in soil temperature and increased water evaporation (one study estimates that residue harvesting can reduce corn derived soil organic carbon by 35% relative to what is retained (Wilhelm and Cushman, 2003). Other studies have found soil organic carbon with corn crops is greatest under no till systems (residues remain in the field) and the lowest in no till when stover is removed (Wilhelm and Cushman, 2003). Roots are the largest contributor to soil organic matter. In fact, one of the benefits of perennials such as switchgrass is that after harvesting its extensive root system grows and sequesters more carbon in the soil.

The timing of the harvest can also be important. Trees are harvested in the winter and the leaves are not removed from the area. In addition, tillage may play an even greater role in the release of soil carbon than residue removal. Leaving some residue on the ground and planting crops which cover soil after harvest can help to limit the problem. Farm machinery running on diesel produces greenhouse gases and the pre-harvest burning of sugarcane (common crop management practice with sugarcane) releases as much as 1/3 of crop biomass into the air as CO_2 with some amount of CH_4 and NO_X (represents the loss of cellulosic biomass that could be used as process energy to offset fossil fuels).

2.4 Refining Feedstocks Into Biofuels

Conversion efficiency, energy input and output, source of process energy (petroleum versus renewable) and emissions are the significant factors to consider in refining which impact climate and the environment. Significant amounts of energy (process heat, mechanical and electrical) are needed for refining. This energy is usually derived from fossil fuels both directly and for electricity generation. Crop residues could be burnt to generate electricity and steam, reducing the need for external energy inputs. In Brazil, bagasse is used as boiler fuel for energy production, enabling mills and distilleries to be almost energy sufficient and sell excess electricity to the national grid. Transitioning to renewable energy this way could significantly reduce lifecycle greenhouse gas emissions associated with biofuel production, particularly if it replaces coal.

For biofuel plants which produce an array of co-products (animal feed or glycerin and fatty acids) the greenhouse gas emissions are shared (the amount attributed to biofuels is reduced), co-products could replace competing products. For example, animal feed made while refining corn to ethanol could reduce the need to grow corn specifically for animal feed (energy saved by the biofuel production process). Lignocellulosic co-products such as straw could be converted into more fuel using 'next generation' technologies, which hold the promise of saving significant amounts of energy.

The production and emission of greenhouse gas calculations will be guided as to how the net energy needs for co-products and fuel are apportioned. Fulton et al., (2004) looked at the greenhouse gas emissions of ethanol from corn and postulated that co-products reduced the net emissions from ethanol by 5–15%. In fact, co-product credits for rapeseed methyl ester (RME), including animal feed and glycerin ranging from 5 to 14% (Armstrong et al., 2002).

Processing biomass into fuel uses large quantities of water. For example, in biodiesel production, water is used to wash plants and seeds for processing and then to remove soap and catalyst from the biodiesel. Sheehan et al., (1998) estimated the water usage for typical US soybean crushing to be 19kg per tonne of oil produced. A tonne of soybeans yield on average 170 kg of crude de-gummed soybean oil, 760 kg are made of soy meal and the remaining 70 kg is made up of non-hazardous remains (air, solid, liquid waste). The primary contaminant in the wastewater is soybean oil. Ethanol requires a tremendous amount of water for processing and evaporative cooling to keep fermentation temperatures at 32–33C. In Brazil, each tonne of sugarcane requires approximately 3900 liters for processing

(Dias De Oliveria et al., 2005). For starchy grains the amount of water fed to the hydrolysis step must be similar for all feedstocks (more water is needed for less starchy grains than for starch rich grains as corn).

From ethanol, processing large volumes of nutrient rich wastewater must be treated or recycled; if it is released to the rivers it will speed eutrophication and negatively impact the water's dissolved oxygen content. In addition, washings from sugar mills put a huge amount of organic matter into local waterways. In Brazil 1 liter of ethanol produces 10–15 liters of stillage (vinasse), which is hot and corrosive with a low pH and a high mineral content (Kojima and Johnson, 2005). In the past vinasse was released to rivers causing enormous fish kills. Nowadays the practice has improved. Vinasse is mixed with recycled wastewater and used for irrigation and fertilizer (regulated by law, it is important to know the height of the water table before instituting such measures). If used extensively vinasse-like fertilizer can cause the eutrophication of surface waters due to high nutrient loads. Filter cake, another waste stream from ethanol refining, is used as fertilizer. These initiatives have helped to reduce Brazil's dependence on petroleum-derived fertilizers and to make use of wastes that would normally end up as pollutants.

In the US, ethanol processing plants have sent syrup, bad batches of ethanol and sewage into streams. While laws exist to prevent such a practice they are not always clear and are subject to interpretation leading some plants to circumvent them. Efforts are ongoing to develop new water quality standards and close the loopholes. Fortunately the problem of nutrient loading and biological oxygen demand (BOD) can be resolved by installing digesters to treat the organics. Standard wastewater treatment technologies can eliminate almost all of the pollutants and over 95% of the water could be re-used (reducing the amount of water for processing); the remainder undergoes further treatment before release.

As the scale of ethanol production ramps up, municipal wastewater treatment plants (WWTPS) will have to be upsized to handle the increased flows from high capacity plants (110,000–150,000 m^3 of ethanol per annum). Waste heat rejected from the fermentation process via cooling water to rivers and streams can kill fish and alter ecosystems. Alternatives exist for removing excess heat through evaporation, dry cooling and cogeneration. Bio solids (sludge, ash *etc.*), waste products from the refining process, could be returned to fields as natural fertilizers if they are non-toxic. Biorefineries will also have to identify the means to treat the large amounts of wastewater that will be necessary (Kaparaju, et al., 2009).

Emissions from biorefineries include SO_X, NO_X, CO, CO_2 VOC, particulates. Biodiesel production uses methanol and emissions may include

air, steam and hexane, which is used to extract oil from plant and seeds. If non-renewable energy sources are used, pollutants associated with fossil fuels are released into the air. As plant sizes increase air emissions, odors and wastewater discharges are expected to rise, however, through regulations and pollution abatement technologies, emissions associated with biofuel refining can be minimized. In Brazil, most mills and distilleries, if not all, are self-sufficient in their energy needs (thermal, mechanical, electrical) by combusting bagasse and selling surplus generation to the national grid. Agricultural and forestry residues can be used to produce heat and power. However, sufficient residues must remain in fields and forests to maintain organic matter and nutrients in the soil.

2.4.1 Transport of Feedstocks and Fuel

Biomass feedstocks are normally transported by truck from the fields to the biorefinery (this mode of transport does not benefit from an economy of scale). This biomass contains unwanted water, fiber and protein, which increases transport energy requirements. Transport by train or pipeline (where feasible) could significantly reduce emissions. As global trade in biofuel ramps up, long distance transport will become an important factor for biofuels. At the same time, the distances the feedstocks and fuels are transported may have only a small impact on life cycle CO_2 equivalent emissions because the net energy requirements for long distance transport will be offset by larger volumes shipped (economies of scale). Further study is required to establish cost and energy relationships for the shipping of refined solid biomass and biofuels from production sites to biorefineries and finished products to consumers.

While shipping is relatively energy efficient, it is also a major source of pollution. Pollutants include NO_X, SO_2 and CO_2 particulates and a number of highly toxic substances such as formaldehyde and polyaromatic hydrocarbons, which are released near coastlines where they can easily be transported over land. Spills and evaporation at production plants, during transportation, from above and below ground storage tanks, during fueling and storage from a vehicle's fuel system are all potential release points for atmospheric emissions.

Neat biofuels are distinctly less toxic than spills of petroleum fuels. Biodiesel has a low vapor pressure so evaporative emissions may not be a particular concern. Neat ethanol has a low Reid vapor pressure (RVP) and when stored as a pure fuel or an E85 blend, its vapor pressure is lower than gasoline and thus has fewer evaporative emissions (Larson, 2005). Low level blends of ethanol and gasoline tend to increase the vapor pressure of

the base gasoline to which the ethanol is added. Blends up to about 40% ethanol have higher evaporative emissions than either of the two fuels on their own. Fuels mixed by splash blending (lower level blends) have the potential for increased evaporative emissions (refueling and from use) and ozone pollution. Evaporative emissions peak at blend levels of 5–10% and then start to decline (the first few % of ethanol causes the biggest jump in volatility).

When blending with ethanol, using base gasoline with a lower vapor pressure usually controls emissions from higher vapor pressure, increasing the cost and reducing production levels. In the US, reformulated gasoline programs have set caps on vapor pressure that take effect during high ozone seasons in areas that do not meet ambient air quality standards for ozone (Quirin et al., 2004).

Ethanol and biodiesel fuels offer significant environmental benefits by dramatically reducing emissions of volatile organic compounds (VOCs), and are less toxic than petroleum fuels. Both are biodegradable and breakdown readily reducing their negative impact on soil and water, making then highly suited for marine and farm uses, among others. Biodiesel is far more water soluble than petro-diesel (marine organisms will survive in greater concentrations of biodiesel as opposed to petro-diesel). Such benefits help to promote its usage especially where pollution to surface and groundwater sources have impacted biodiversity, drinking water and soil resources. It has been shown that biodiesel in biodiesel petroleum blends speeds up biodegradation rates as well, which is not the case for ethanol. Although the ethanol degrades rapidly in soil and water, it depletes the oxygen available and slows the breakdown of gasoline (harmful chemicals persist longer in the environment and travel further affecting a greater area).

2.4.2 Combustion

The combustion of biofuels releases CO_2 but because the emissions are part of the natural fixed carbon cycle and absorbed by plants during growth, they do not contribute to new emissions of CO_2. NREL estimates biodiesel from soybeans emit 10% more CO_2 than does petro-diesel due to more complete combustion and 'the concomitant reductions in other carbon-containing tailpipe emissions; however, most of this is renewable or recycled in growing soybean plants (Sheehan et al., 1998). The level of exhaust emissions from combusting ethanol or biodiesel depends upon the fuel (feedstock and blend), vehicle technology, vehicle tuning and driving cycle (Pimentel and Patzek, 2005). Most studies support a reduction in pollutants as well as toxic emissions when compared to petro-fuels.

Ethanol does not contain sulfur, olefins (smog), benzene (carcinogenic) or other aromatics (smog) (all found in gasoline) all of which negatively affect air quality and threaten human health. Ethanol blends also reduce emissions of 1,3-butadiene, toluene and xylene. When ethanol combusts the toxic emissions acetaldehyde, formaldehyde and peroxyacetyl nitrate (PAN), although there are increases relative to straight gasoline, most is emitted as acetaldehyde which is less reactive and less toxic than formaldehyde (Butkus and Pukalskas, 2004; Fulton et al., 2004). These pollutants are as a result of incomplete combustion. Ethanol blended gasoline increases fuel oxygen content, the hydrocarbons in the fuel burn more completely, reducing emissions of carbon monoxide and hydrocarbons. Brazil was one of the first countries in the world to eliminate lead entirely from its gasoline as a result of its national ethanol programme *Proalcool.* Ethanol blended with diesel can provide substantial air quality benefits (10 to 15% v/v ethanol in gasoline resulted in lower emissions of particulate matter, carbon monoxide, and NO_X when compared to neat diesel fuel). Exhaust emissions testing at high blends are conflicting, additional studies need to be undertaken to bring clarity to the situation.

Biodiesel whether pure or blended resulted in lower emissions of most pollutants (particulates, sulfur, hydrocarbons, carbon monoxide, toxins) relative to diesel (Leenus Jesu Martin et al., 2011). Emissions are expected to vary with engine design, condition of vehicle and quality of fuel. In biodiesel-diesel blends, as the percentage of biodiesel increased, pollutants decreased with the exception of NO_X emissions (Wang et al., 1999). USEPA study of biodiesel determined the impact on emissions vary depending upon type (feedstock) of biodiesel and type of diesel. From the study, animal based biodiesel did better in the study than plant based biodiesel with regard to reductions in NO_X, CO, particulates.

During 2000, biodiesel became the first alternative fuel to successfully complete testing for tier 1 and tier 2 health effects under the US Clean Air Act (tests determined that, with the exception of minor damage to lung tissue at high levels of exposure, animals observed in the study suffered no biologically significant short-term effects associated with biodiesel (Quirin et al., 2004). The impact of ethanol and biodiesel on NO_X emissions is currently a topic of debate among the scientific community, as a number of studies have given inconsistent results.

Literature points to the fact that the air quality benefits of biofuels may have more of an impact in developing countries where vehicle emission standards are non-existent or relaxed and where many of the vehicles are usually underpowered, over-fuelled, overloaded and not well maintained. Further research is required to ascertain such effects on emission levels.

2.4.3 Results of Well-to-Wheel Analyses

Well-to-wheel analyses of a number of biofuels have been published (Table 2.1). In this table, the percent change in greenhouse gas emissions of biofuels is compared to conventional fuel.

As can be seen, some studies specifically indicated that land use changes were accounted for in calculations. Researchers have postulated that these

Table 2.1 Well-to-wheel Analysis of Greenhouse Gas Emissions Compared to Conventional Fuel.

Source	% Change
Bioethanol vs Conventional Gasoline	
Corn	–45%
E5 wheat	–64%
E85 Black locust	–97%**
E85 Eucalyptus	–40%**
E85 Poplar	–50%**
Mexican sugarcane	–26%*
Miscanthus	–40%
Rice straw from Koshihikari variety	–128% – –93%**
Rice straw from Leafstar variety	–128% – –55%**
Sugarbeet	–150%
Switchgrass	–80%
Biodiesel vs. Conventional Diesel	
Camelina	–70%*
Canola	–2%*
Jatropha curcas	–40–50%
Soy	–40%*

Notes: * = specifically indicated that land use changes were accounted for in calculations; ** = CO_2 only considered

Sources: Garcia and Manzini, 2012; Gonzalez-Garcia, et.al, 2012; Gnansounou, Dauriat, Villegas and Panichelli, 2009; van der Hilst, et al., 2012; Krohn and Fripp, 2012; Kumar, et al., 2012; Roy et.al, 2012; Wang, Huo and Arora, 2011.

results more accurately reflect the percent change in greenhouse gas emissions of biofuels compared to conventional fuels (Haberl et al., 2012). Other studies did not explicitly calculate the percent change in greenhouse gas emissions, but calculated the length of time it would take to pay off carbon debts through reduction in greenhouse gas emissions and the resultant savings. The deforestation of tropical rainforests will take an estimated 86 years of palm biodiesel production to repay the debt and deforestation of tropical grassland is estimated to take 17 years of sugarcane ethanol production to pay off its carbon debt (Silva Lora et al., 2011). Current results indicate that bioethanol has a larger effect on greenhouse gas emissions compared to biodiesel. However, the high numbers for bioethanol typically depend on low fertilizer use, efficient water use and low levels of mechanized labor.

2.4.4 Reducing the Climate Impact of Biofuels

The potential to reduce greenhouse gas emissions associated with biofuels will depend on (1) improved yields with existing feedstock (2) improved refining process efficiencies (3) new energy crops (4) new technologies and an increase in added-value products.

2.4.4.1 Improved Yields

Currently, product yields of biofuels are low, being plagued by difficult separations and poor reaction kinetics. For example, for every bushel of corn, you only get 2.72 gallons of ethanol, for every dry ton of switchgrass, 95 gallons of ethanol and for every bushel of soybeans, 10.1lb of biodiesel (Wang et al., 2011). Although significant yield improvements have been achieved with a variety of crops, sugarcane, corn, soybean, oil palm and willow, advances are expected to continue. These improvements are due to several factors such as hybridization, genetic improvement, crop management and farming conservation. As crop yields improve, the amount of land and inputs required to produce a given amount of biofuel should decline, reducing the climate impact. Yields for miscanthus, switchgrass and other energy grasses are expected to increase (so far energy crops have not been bred intensively, potential exists in a doubling of their productivity).

2.4.4.2 Improved Process Efficiency

Improvements in process efficiencies (technology advancement) offer further reductions in greenhouse gas emissions as seen in both corn ethanol

yields in the US and sugarcane ethanol yields in Brazil (corn moved from 9 liters per bushel (1970s) to 9.8–10.6 liters per bushel (mid 2000s) and sugarcane moved from 73 liters per tonne (1975) to 85 liters per tonne (1995) and then to 90 liters per tonne (2002). It has been estimated that there has been a near tripling over the last 30 years from 2000 liters of ethanol per hectare of sugarcane 2000 liters (1975) to 5000 liters (1999) to 5900 liters (2004) (Nastari, 2005). Some put the current yield as high as 7000 liters per hectare under good growing conditions (Filho, 2005).

The Dutch Energy Agency (NOVEM) and Arthur D. Little (ADL) estimated that life cycle CO_2 equivalent emissions would decline significantly for many processes by the 2010–2015 period, with most pathways leading to high reductions relative to gasoline or diesel. In many cases, greenhouse gas emissions reduction would exceed 100%, due mainly to the use of biomass for process energy. They projected that the greatest reductions would result from the production of cellulosic ethanol using enzymatic hydrolysis in biorefineries, but that biomass gasification and conversion to final fuels such as diesel and DME would provide similar reductions. It has been estimated that that greenhouse gas benefits will increase with time, however, noted higher conversion efficiency will mean fewer co-products reducing advantages somewhat (Quirin et al., 2004). It will be important for policy makers to balance the benefits from technology improvements against the rising cost of obtaining feedstock supply through unsustainable means (for example destroying wild ecosystems to grow palm oil and soybean).

2.4.4.3 New Energy Feedstocks

As previously discussed, improvements in crop yields and process efficiencies could bring about a reduction in greenhouse gas emissions but they will not be enough to change relative benefits of given types of biomass and land-use changes (Tampier, 2004). Such improvements will be hard pressed to outweigh the negative impacts of expanding feedstock supply and associated land use if not sited, selected, planted and managed in a sustainable manner. This provides the impetus for new energy crops such as short rotation forests and perennial grasses, which offer a significant potential to reduce the lifecycle emissions from biofuels.

As discussed elsewhere (Section 2.3.1.1 – Land Use) such crops, if planted in place of annual crops or on degraded land, can increase the amount of biomass above and below ground. Perennial herbaceous species as switchgrass hold the promise of the lowest life-cycle greenhouse gas emissions because these crops sequester carbon in the ground (assuming they are grown on poor soil or displace annual crops); in addition they

require less fertilizer and irrigation effectively reducing N_2O and CO_2 emissions.

Short rotation (SR) forestry and logging residue can reduce greenhouse gas emissions because the trees increase carbon sequestration in the soil and their biomass and N_2O emissions drop because of the reduced use of fertilizers. Further research is needed to quantify the amount of residue that could be safely removed from the forest without adversely impacting greenhouse gas emissions.

Cellulosic and other feedstocks such as manures, biodegradable organic fraction of municipal solid waste, wastewater treatment plant sludge (WWTPS) and restaurant grease could dramatically reduce the lifecycle greenhouse gas emissions associated with some biofuels while providing the added benefit of reducing the amount of land and other resources required to store or dispose of these products. Quirin et al., (2004) makes the case that alternative uses for waste must be factored in the lifecycle impacts of using them as biofuel feedstock a practice that is not normally done.

2.4.4.4 New Technologies

Cellulosic conversion technologies hold the promise of dramatically increasing yields per unit of land, reducing fossil fuel input and reducing greenhouse gas lifecycle emissions. The feedstock can come from crop residue or energy crops. Larson (2005) expects advanced biochemical pathways (cellulosic conversion technologies) and gasification Fischer-Tropsch synthesis of diesel or dimethyl ether (DME) from perennial crops could result in reductions of 80 to 90% and higher. Fulton et al., (2004) projects net greenhouse gas emissions can even exceed 100% if the feedstock uses more CO_2 in photosynthesis than the CO_2 equivalent emissions released during its full lifecycle. It is believed that next generation feedstocks and processes can result in substantial reductions compared to petro-fuels assuming that all major production processes and the use of fertilizers become more efficient and that biomass is used as process energy (Delucchi, 2005).

These projections in reduction in greenhouse gas emissions range from 70 to 90% v/v relative to gasoline (most of which come from engineering studies since few large-scale production facilities exist). It has been estimated that cellulosic ethanol made from woody biomass could achieve reductions larger than those from herbaceous biomass (Wang et al., 1999). Advances in cellulosic conversion technologies through biochemical (enzymatic hydrolysis and microbial digestion) and thermochemical

pathways involving integrated gasification and Fischer-Tropsch synthesis processes hold great promise for reduction in greenhouse gas emission.

Micro-algae offer the potential for large sources of feedstock for biodiesel production that could result in significant emissions reduction. It is believed that algae can produce far more oil per hectare than any other biodiesel feedstock. A promising development is the idea of micro-algae colonies that could be used to clean up agricultural waste and power plant emissions. Hydrous anaerobic pyrolysis (mimics the geological conditions that created crude oil) and carbon capture combined with storage all show promise of enabling reductions in greenhouse gas emissions in excess of 100% v/v.

2.4.4.5 Co-products

Biofuel plants produce an array of co-products (animal feed or glycerin and fatty acids) and the greenhouse gas emissions can be shared across the co-products and not all are attributed to biofuels. If excess electricity is generated it can be sold to the grid and possibly offset fossil-generated power. As biofuel usage and production ramps up to meet global transport energy demands, the potential exists to significantly reduce greenhouse gas emissions or exacerbate the threat of global warming (climate impacts depend on effects such as land use changes, choice of feedstock, crop management and refining). The greatest potential for reduction in greenhouse gas and associated cost is in the next generation feedstocks and biofuels (advanced cellulosic technologies).

Government policies must focus on commercializing these advanced technologies and driving down their cost, protecting virgin lands and encouraging sustainable feedstock and management practices. Further research is needed to fill the gaps in the existing body of lifecycle studies (analyses relevant to developing countries that cover the range of the biofuel feedstocks and pathways, better understanding of N_2O emissions and impact on climate, land use efficiency *etc.*). Any plan to promote the production and use of biofuels on a large scale to displace petro-fuels must be part of a strategy to reduce energy consumption in the transport sector (lighter, more fuel efficient vehicles, smarter urban design and mass transit).

2.5 Impact of Growing Biomass

Biomass energy has the potential to supply a significant portion of America's energy needs, while revitalizing rural economies, increasing

energy independence and reducing pollution. Rural communities could, through biomass farming, become entirely self-sufficient when it comes to energy, using locally grown crops and residues to fuel cars and tractors and to heat and power homes and buildings.

In fact, agricultural activities generate large amounts of biomass residue. While most crop residues are left in the field to reduce erosion and recycle nutrients back into the soil, some could be used to produce energy without harming the soil. Other wastes such as whey from cheese production and manure from livestock operations can also be profitably used to produce energy while reducing disposal costs and pollution. In addition, growing energy crops, grasses, tress and oil plants could make many farms profitable.

However, issues such as availability of land, negative impact on flora, fauna, ecological diversity and food security are some of the considerations that must go into the planning for the large scale cultivation of biomass. The production of lucrative crops in developing countries offers potential pathways out of poverty and also raises significant environmental and social questions (oil palm development in Indonesia linked to widespread economic development alongside extensive deforestation, pollution and conflicts over land). As discussed, biofuels present an opportunity to reduce greenhouse gas emissions, however to derive the benefits, planners must always be cognizant of the effect of biomass production on land use, particularly natural grasslands, wild savannahs, rainforests (wild ecosystems) and its impact on habitat, biodiversity, water, air and soil. This raises the urgent need to develop biofuels in an environmentally sustainable manner; similar concerns arise with current first generation feedstocks.

On the other hand, energy crops have the potential to reduce the environmental load imposed by intensive agricultural cropping by maximizing total energy yield per hectare rather than the oil, sugar, starch content of crops, diversifying plant varieties, reducing fertilizer and pesticide usage, stabilizing soil and increasing organic soil carbon.

2.5.1 Habitat Destruction

The expansion of agriculture, resulting in habitat destruction, is one of the greatest threats to world biodiversity, especially in tropical regions. Intensification of farming practices, leading to the degradation of agricultural and semi-natural habitats, is also causing declines in biodiversity across huge areas. Growing human populations, increasing demand for animal protein and policies promoting biofuel production are the underlying causes for these trends. Since biofuels can be made from a wide range

of plants, the enthusiasm for biofuels as a solution to climate change and energy security may be unfounded, given the associated risks of large-scale environmental destruction and increased emissions through conversion of natural and semi-natural habitats such as forests, peat lands and grasslands.

In fact, it has long been recognized that growing biomass is probably the most environmentally disruptive stage of biofuel production because of the threat posed by expanding the amount of cultivated land leading to the irreversible conversion of virgin ecosystems (Cook et al., 1991; Campbell and Doswald, 2009). Deforestation leads to the loss of habitat, disappearance of species and disruption /loss of ecosystem functions (such as hydrological aspects and climate). Unfortunately the demand for biofuels has spurred the expansion of agriculture onto virgin lands and intensification of land use in others. The rainforest ecosystems of Brazil, Malaysia and Indonesia are at the greatest risk in addition to the savannahs of southern Brazil. These regions are of immense value because of the diversity of their flora and fauna. Government planners must develop a clear land use policy to protect their natural forests, grasslands and wetlands from becoming giant monocultures.

Sugarcane has a poor environmental track record, with the greatest consequence being the loss of biodiversity. An example of this can be seen in the Caribbean, where diverse ecosystems were lost largely to the importance of growing sugarcane in the islands' colonial past. In Brazil, the expansion of sugarcane and soybean production to meet the demand for ethanol and biodiesel, sugar and soy in food and feed markets have led to giant monocultures which have replaced pastureland and small farms of varied crops. This has led to the clearing of rainforest to open up new pastureland for livestock rearing.

The Brazilian *cerrado* a wild central natural savannah (approximately 25% of Brazil's land area) is considered the natural expansion for sugarcane and soybean cultivation. However, it is home to half of Brazil's native species and a quarter of its threatened species. Expansion into such a complex, diverse and sensitive ecosystem could result in irreversible ecological damage. Soybean plantations have already replaced vast stretches of cerrado and rainforest. Brazil's soybean cultivation increased from 11.7 million hectares (29 million acres) in 1994/1995 to 22.3 million hectares (55 million acres) in 2004/2005 and, like sugarcane, initially expanded by acquiring small farm holdings to grow acreage.

The Brazilian rainforest is also at risk, the construction of ethanol plants along the Upper Paraguay River (state of Mato Grosso do Sul in the country's southwest) could threaten the environmental balance of the Pantanal, the world's largest wetland area. Transportation networks now extend into

Brazil's Amazon region to facilitate the flow of sugarcane, soybeans and other products to processing plants and ports; it is more likely that these crops will expand into sensitive areas, so a balance must be struck between environmental preservation and cropland expansion. To date, it is estimated nearly 20% of the Amazon, home to an estimated 30% of the world's species of plants and animals, has been burned or otherwise destroyed much of it due to large-scale agriculture.

In Southeast Asia (Malaysia and Indonesia) the expansion of palm oil plantations has resulted in the destruction of large tracts of rainforest. Rather than planting on wasteland or impoverished agricultural lands, natural forests are being felled; this is seen as a more attractive prospect as it requires less fertilizer and the timber can be sold. This indiscriminate clearing of virgin forest poses a tremendous threat to the region's biodiversity. Environmentalists point to the fact that the expansion of palm oil plantations in Indonesia and Malaysia is consuming the rainforests at an alarming rate and destroying the habitat of the orangutans (expected to disappear over the next 10 years) (Matthew, 2005).

Other groups have alluded to the fact that the EU demand for biodiesel could accelerate this deforestation and undermine the environmental benefits for promoting biofuels (gains from biofuel usage in EU could be eroded by destruction of rainforest in south east Asia). The palm oil industry must be wary of its actions and mandate that new plantations be established on existing cropland (possibly displace crops of annual grains, vegetables and other short term crops where possible), wastelands or degraded agricultural lands and desist from the indiscriminate cutting of wild forests and the destruction of habitat. Oil palm has also been associated with complaints of extensive "losses of land by indigenous people and a failure to achieve sustainable livelihood improvements for small farmers," which, it is anticipated, will lead to future poverty for many.

While the destruction of the world's tropical rainforests and natural savannahs might be the greatest land use concern due to the effect on biodiversity, biomass production expanding onto cropland, wild lands and conservation reserve land is of a major concern as well. Feedstock production could threaten the diversity of farmland and result in large tracts of monoculture plantations as has occurred in Brazil with sugarcane and soybean. In the US, rising demand for soybeans and corn has resulted in a 'duo-culture' cropping style. Expansion of US fuel ethanol markets could have planners contemplating putting millions of hectares of conservation reserve land under biomass production (possibly increasing erosion in rough sloping and in difficult to plant areas) and this could eliminate wildlife gains made over the years.

It is estimated that 5% v/v of EU transport fuel needs could be met by growing energy crops on currently unproductive agricultural lands, while forests, grasslands and the use of wastes could provide more (the EU is considering sustainability impacts and expanding nature conservation areas, leading to a reduced biomass resource base). Given the threats to both land and wildlife, it will be necessary to carefully manage how lands that have been set aside are returned to agricultural production (as demand for biofuels increase, if feedstocks are unavailable from major producers, they will be cultivated in other countries that may not enforce good land use practices).

As crop yields increase, land requirements per liter of biofuel will decline, along with the impact on habitat and wildlife (requiring that less virgin land to be cultivated). ‘First generation’ energy crops grown for their sugar, starch, oil content will eventually make way for ‘next generation’ cellulosic biomass (increased leaf and stem mass) where plants are now aggressively bred to increase yields of cellulosic feedstock (corn stover or switchgrass).

2.5.2 Minimizing Land-Use and Impact on Wildlife

Planners must minimize the hazard posed to land and habitat by biomass cultivation and institute control measures. Expanding plantations onto degraded lands (unsuitable for agriculture), use of agricultural and forest residues and wastes as feedstocks, all offer significant potential for biofuel production. For example, India has over 400,000 hectares of wasteland (0.13% of its land area) on which it proposes to cultivate jatropha and pongamia.

Although this is not expected to affect plant and animal diversity, Indian planners must be aware of the fact that when wasteland resources are exhausted for growing energy crops, there will be a tendency for farmers to expand into natural forest ecosystems. This must be combated by a proper land use policy. Jatropha is also used in Mali to reverse desertification, provide income and fuel (for electricity and transport). Furthermore, other researchers have found that using marginal or degraded lands to grow energy crops can lead to unfeasible chains due to negative traits such as a lack of easily available water, poor organic matter in soil, excess sloping, long distance transport routes and pollution in the soil from previous use (Fahd, et al., 2011). As such, the benefits and disadvantages must be carefully weighed when marginal lands are used.

Oilseed and starch crops grown in temperate climates use land inefficiently and consume large amounts of fertilizer and pesticides when compared to tropical oil and sugar plants. Although this points to greater land

efficiency, the tendency has been to expand into wild habitats. Biomass crops are of concern when they are grown as monocultures and/or with genetically modified organisms.

Commercializing cellulose to ethanol conversion technologies and gasification with Fischer-Tropsch technology can convert woody biomass and waste products into gases and then liquids including lignin (something that is difficult for enzymes to convert), which has the potential to produce more fuel per tonne of biomass and provide a feasible option for reducing land use.

Cellulosic technologies will use perennial energy crops (that can provide a more diverse habitat for wildlife), agricultural and forest residues as feedstocks for biofuels. Forest residues per se do not create waste problems because they are recycled naturally, although research is required to ascertain how much can safely be removed without negatively impacting soil quality (Section 2.3.1.1, Land Use). Many of the cellulosic energy crops (perennial grasses, woody biomass) offer greater diversity and variability and can be grown economically on less valuable land with fewer inputs. These crops could be grown on lands that are no longer required for food production, for example, on US cropland that used to grow corn for ethanol or EU cropland that used to grow rapeseed, sugar beets, wheat and sunflower for biodiesel production. Research will have to be undertaken to identify native species of grasses (and to avoid invasive species) suited to soil and climatic conditions (species may need to be drought resistant and fire tolerant) for the region.

Some experts believe high lipid (oil rich) micro-algae can be grown on a large scale atop buildings and in deserts and hold the key to large scale biodiesel production. In addition, waste products (waste oils, restaurant grease and biodegradable organic fraction of municipal solid waste) can be converted to fuel, saving valuable land area (and deferring the setup of landfills).

Despite the enormous ecological costs that could arise from increasing biomass feedstock crops, perennials can provide a stable environment, encourage increased wildlife populations and promote diversity. Energy crops such as woody crops and switchgrass cannot substitute for natural forests and prairies nor support the same mixture of bird and small mammals. Perennials such as short rotation tree plantations might be no better for diversity than annual crops if large tracts of monocultures replace numerous small fields of diversified crops. However they can serve some of the functions of natural systems and enhance regional diversity if planted in landscapes dominated by annual crops.

Biomass crops could be used as buffers for wildlife along waterways between forests or natural grasslands and annual crops, or as protective

corridors that allow plants and wildlife to move from one natural area to the next (Schiller, Tolbert, 1996). Tree plantations sited alongside natural forests can expand the habitat for forest bird species even in regions dominated by agriculture (Perlack, 1995). Intercropping with grasses and trees can help to maintain the diversity of plants and animals on energy plantations, while also reducing soil erosion (Graham, Liu, English, 1995). Patches of vegetation left because of less frequent rotational harvesting also result in greater diversity. Forests and grasslands that are structurally and species diverse can help to reduce the negative impact of weeds, insects and diseases (IEA, 2002).

2.5.3 Impact on Soil Quality

When land is converted from natural cover to intensive agriculture, its organic content decreases over time. Fertilizers are used to add nutrients and pesticides to control weeds, insects and blights. Nitrogenous fertilizers cause acidification of soils and surface waters. Intensive farming causes soil erosion especially in areas that experience prolonged dry periods followed by heavy rains, on steep slopes and unstable soil. Erosion causes a loss of organic soil substances (nutrient depletion) and eutrophication in nearby rivers (impact plants and wildlife). Intensive harvesting methods can compact the soil and impact soil structure, biodiversity and cause waterlogging, deplete soil nutrients and organic matter and affects the soil's capacity to hold moisture; meanwhile, short crop rotation periods reduce soil fertility and soils exposed during and after harvesting are vulnerable to erosion. Consequently, the frequency of harvesting and replanting are significant in determining environmental impact.

The removal of crop residue can also negatively impact soil quality, increase greenhouse gas emissions through the loss of soil carbon and promote erosion; the amount that can be removed sustainably should be studied as it varies for each crop type (Cherubini and Ulgiati, 2010). Residual removal also impacts the rate of physical, chemical and biological processes in the soil (fluctuations in soil temperature and increased water evaporation) which affects plant growth.

Perennial energy crops such as some trees and native grasses improve soil quality, increase soil cover (which reduces erosion), reduce soil disturbance, improve organic matter and carbon levels, increase soil biodiversity and reduce chemical inputs (materials such as fertilizers and pesticides). For instance, some tree species grown on previously degraded lands help to minimize evaporative water loss and improve soil moisture conditions, making the planting of crops possible on once degraded land. Tree species

that fix nitrogen (*leucaena* and *acacia* trees) reduce the need for nitrogenous fertilizer, improve soil quality and produce fodder. Oilseed trees like jatropha and pongamia are drought tolerant and thrive on impoverished soil. They appear suited for much of Africa, Asia, the Middle East and the islands in the Pacific and Indian Ocean. These hardy plants produce a high oil yield and improve soil quality.

Leaves, organic matter (both of which improve soil fertility and physical properties) and tree cover protect the soil from erosion. The positive effect that trees have on soils is the ability of the tree-soil partnership to retain water. Palm trees offer some protection to the soil from erosion, grow in impoverished soils and establish tree cover fairly quickly. Perennial grasses have the benefit of extensive root systems, do not require tilling, minimize soil erosion, help to increase soil productivity, minimize chemical inputs (reduce chemical run-off) and are drought resistant (jatropha and pongamia) when compared to more intensive crops as wheat, corn and soybean. Perennials also thrive on wasteland or erosion prone lands and provide habitat for birds and small mammals (if allowed to grow for some years before harvesting).

Long-term soil productivity, minimum chemical input, proper land use and crop management must be at the forefront for building a sustainable biofuel programme. Conservation tillage and no till planting, which avoids ploughing, minimizes soil erosion, fertilizer usage and energy associated with this activity must become a more common practice. 'Double cropping' a technique where at least two crops and two harvests are done annually on the same field has seen some success in Germany. The benefits are no ploughing, year round ground cover, little to no chemical pest management and the use of crop residues to enrich the soil. The mixing of crops can result in the following positive benefits as well: reducing the nutrient input, enhancing diversity of landscapes and crops, minimizing heavy machinery and water, creating year round coverage and decreased impact on soil, providing shelter and food for wildlife and reducing the susceptibility of disease and pests.

Intercropping, crop rotation and bio-fertilizers can help to recirculate nutrients in the soil. In Brazil it was expected that long-term cultivation of sugarcane would reduce soil productivity, however, the opposite has been true most likely due to good soil preparation, superior varieties of cane and the recycling of nutrients through the application of nutrient rich water left over from sugar milling and ethanol distillation to the fields. In addition nutrients can also be returned to fields via non-toxic ash produced during processing.

Organic matter and nutrients can be maintained in the soil if sufficient biomass remains in the field when crops are harvested. As discussed, while some agricultural residue is safe to remove, it is important to leave some on the ground to minimize soil loss and run-off; the amount that can be removed sustainably should be studied as it varies for each crop type. In forests, logging residues reduce exposure of the soil to erosion. Dead wood and residues help to regulate water flow and nutrients through the forest, tree roots and branches protect the soil. Tree foliage contains a higher concentration of nutrients than wood so the extent to which foliage remains will enhance the forest health. Apart from residue removal and tillage, soil is more likely to be disturbed by heavy harvesting machinery when it is wet. Harvesting when the soil is dry or frozen could minimize damage.

2.5.4 Impact on Water Resources

Growing biomass affects water supplies greatly; large amounts of water are required for growing conventional biomass sources (depleting freshwater resources) and second run-off from fields can pollute waterways and threaten wildlife (eutrophication). As biofuel demand ramps up, water consumption will rise where conventional feedstocks are grown. Heavy water usage during dry spells intensifies water shortages and may negatively impact river ecosystems. The need for irrigation can place additional pressure on already strained water resources. Irrigation may result in soil loss and the leaching of nutrients and fertilizers from the soil.

Water quality (surface and groundwater) is also affected primarily by run-off and the leaching of chemical inputs. For example, corn requires more pesticides than other food crops and corn hybrids need more nitrogenous fertilizers than any other crop. Typically plants take up less than half the nitrogen applied to crops in the form of fertilizer. The remainder is dissolved in surface waters, absorbed into groundwater or lost to the air. Eutrophication (the rapid plant growth in water that results in oxygen deprivation) of surface waters from excess nitrogen run-off is a major concern, as is pollution from chemical pesticides.

Biomass crops must be carefully selected to minimize water usage, fertilizers and pesticides so that run-off will have lower concentrations of harmful chemicals. Biorefineries, for example, are expected to not only use large amounts of water, but to also produce large amounts of wastewater with high levels of residual organics and inorganics (Kaparaju, *et al.*, 2009).

Some crops may be able to filter nutrients that leach off adjacent farmlands, ensuring they do not contaminate nearby water courses. Perennial crops and no-till buffer zones adjacent to waterways can reduce the biological and chemical oxygen demand (BOD and COD) placed on watercourses in agricultural areas.

Woody crops that are harvested over longer periods and are well managed can regulate water flows (safeguard against the damage caused by floods and improve water storage in dry regions). The large leaf areas of most woody crops combined with their deep root systems increase evapotransportation and reduce the potential for run-off and leaching (Powlson et al., 2005). There is also the likelihood for negative impacts on local and regional hydrology from the introduction of energy crops. This is an issue that requires further study.

As discussed above, jatropha and pongamia can be grown in arid and semi-arid areas on marginal lands. However, even these crops require some limited irrigation resources (in India it is expected that jatropha plantations will need to be irrigated once a month during the summer for the first two to three years after planting). Nevertheless, if such plants replace more water intensive feedstock crops, there is the potential that water demands per unit of fuel could decline significantly. A further benefit of some oilseed crops such as jatropha and other perennials energy crops is that they tend to require fewer chemical inputs than annual feedstock crops and as a result they have far less impact on water quality than annual grain and oilseed crops do such as rapeseed, soybeans and corn.

2.5.5 Impact on Air Quality

Air pollution results from the combustion of biofuels. In addition, air quality is also affected during the growing process. Diesel powered farm machinery will cause a small amount of air pollution during planting and harvesting. In the case of sugarcane, fields are intentionally burned to remove leaves and to make harvesting the stalks easier. The combustion products are a host of gases and toxic compounds (CO_2, CO, CH_4, N_2O and NO_X), which greatly impact air quality.

Fires in cane fields can spread to other areas and destroy native vegetation. Inorganic nitrogen fertilizers (widely used in biomass cultivation) account for 60% of anthropogenic nitrogen in addition to the cultivation of leguminous crops such as soybeans, which account for about 25% of anthropogenic nitrogen. Not only is nitrous oxide a potent greenhouse gas, it also contributes to ozone depletion.

References

Armstrong, A.P., Baro, J., Dartoy, J., Groves, A.P., Nikkonen, J. and Rickeard, D.J. 2002. "Energy and Greenhouse Gas Balance of Biofuels for Europe – an Update," CONCAWE Report No 2/02, Brussels, April

Baumert, K.A., Herzog, T. and Pershing, J. 2005. "Navigating the Numbers: Greenhouse Gas Data and Climate Policy," World Resources Institute, Washington, DC.

Bell, :L. 2011. *Climate of Corruption: Politics and Power behind the Global warming Hoax*. Greenleaf Book group Press, Austin, Texas.

Butkus, A. and Pukalskas, S. (004). *The Research into the Influence of Ecological Petrol Additives in the Automobile Laboratory*. Transport, 19: 24–27.

Campbell, A. and Doswald, N. 2009. "The Impacts of Biofuel Production on Biodiversity: A Review of the Current Literature." UNEP-WCMC Report. The United Nations Environment Programme World Conservation Monitoring Centre, Cambridge, United Kingdom. December.

Cherubini, F. and Ulgiati, S. 2010. *Crop Residues as Raw Materials for Biorefinery Systems – A LCA Case Study*. Applied Energy, 87: 47–87.

Clay, J. 2004. *World Agriculture and Environment*. Island Press, Washington, DC.

Cook, J.H., Beyea, J. and Keeler, K.H. 1991. *Potential Impacts of Biomass Production in the United States on Biological Diversity.* Annual Review of Energy and the Environment, 16: 401–431.

Dale, V.H., Kline, K.L., Wiens, J. and Fargione, J. 2010. "Biofuels: Implications for Land Use and Biodiversity." Biofuels and sustainability Reports, Ecological Society of America, Washngton, DC. www.esa.org/biofuelsreports.

Davis, S.C. Anderson-Teixeira, K.J. and DeLucia, E.H. 2009. *Life Cycle Analysis and the Ecology of Biofuels*. Trends in Plant Science 14(3): 140–146.

Delucchi, M.A. 2005. "A Multi-Country Analysis of Lifecycle Emissions from Transportation Fuels and Motor Vehicles." Institute of Transportation Studies, University of California-Davis, Davis, California.

Dias De Oliveria, M.E., Vaughan, B.E. and Rykiel, E.J. Jr. 2005. *Ethanol as Fuel: Energy Carbon Dioxide Balances and Ecological Footprints*. BioScience, 55(7):593–602.

Eickhout, B., van den Born, G.J., Notenboom, J., van Oorschot, M., Ros, J.P.M., van Vuuren, D.P. and Westhoek, H.J. 2008. "*Local and Global Consequences of the EU Renewable Directive for Biofuels." Testing the Sustainability Criteria*. MNP Report No. 500143001/2008. PBL Netherlands Environmental Assessment Agency, The Hague, Netherlands.

Fahd, S., Fiorentino, G., Mellino, S. and Ulgiati, S. 2011. *Cropping Bioenergy and Biomaterials in Marginal Land: The Added Value of the Biorefinery Concept.* Energy, 37(1): 79–93.

Fargione, J.E., Hill, J., Tilman, D., Polasky, S. and Hawthorne, P. 2008. *Land Clearing and the Biofuel Carbon Debt.* Science, 319(5867): 1235–1238.

Fargione, J.E., Cooper, T.R., Flaspohler, D.J., Hill, J., Lehman, C., McCoy, T. McLeod, S., Nelson, E.J., Oberhauser, K.S. and Tilman, D. 2009. *Bioenergy and Wildlife: Threats and Opportunities for Grassland Conservation*. Bioscience 59: 767–77.

Filho, A.B. 2005. "The Agri-Energy Option for the Future." Proceedings. Workshop and Business Forum on Sustainable Biomass Production for the World Market, Sao Paulo, Brazil, 30 November-2 December.

Fogg, P.G.T. and Sangster, J.M. (Editors). 2003. *Chemicals in the Atmosphere – Solubility, Sources and Reactivity*. John Wiley & Sons Inc., Hoboken, New Jersey.

Fulton, L., Howes, T. and Hardy, J. 2004. "Biofuels for Transport: An International Perspective." International Energy Agency, Paris, France.

Garcia, C.A. and Manzini, F. 2012. *Environmental and Economic Feasibility of Sugarcane Ethanol for The Mexican Transport Sector*. Solar Energy, 86: 1063–1069.

Gnansounou, E., Dauriat, A., Villegas, J. and Panichelli, L. 2009. *Life Cycle Assessment of Biofuels: Energy and Greenhouse Gas Balances.* Bioresource Technology, 100: 4919–4930.

Gonzalez-Garcia, S., Moreira, M.T., Feijoo, G. and Murphy, R.J. 2012. *Comparative Life Cycle Assessment of Ethanol Production from Fast-Growing Wood Crops (Black Locust, Eucalyptus and Poplar)*. Biomass and Bioenergy, 39: 378–388.

Goreham, S. 2013. *The Mad, Mad, Mad World of Climatism: Mankind and Climate Change Mania*. New Lennox Books Inc., New Lennox, Illinois.

Graham, R.L., Liu, W. and English, B.C. 1995. "The Environmental Benefits of Cellulosic Energy Crops: A Landscape Scale." Proceedings. Environmental Enhancement through Agriculture. Center for Agriculture, Food and Environment, Tufts University, Medford, Massachusetts. November 15–17.

Haberl, H., Sprinz, D., Bonazountas, M., Cocco, P., Desaubies, Y., Henze, M., Hertel, O., Johnson, R.K., Kastrup, U., Laconte, P., Lange, E., Novak, P., Paavola, J., Reenberg, A., van den Hove, S., Vermeire, T., Wadhams, P. and Searchinger, T. 2012. *Correcting a Fundamental Error in Greenhouse Gas Accounting Related to Bioenergy.* Energy Policy, 45: 18–23.

Howarth, R.W., Bringezu, S., Bekunda, M., de Fraiture, C., Maene, L., Martinelli, C., Maene, L. and Sala, O. 2009. "Rapid Assessment on Biofuels and Environment: Overview and Key Findings." In: Biofuels: Environmental Consequences and Interactions with Changing Land Use. R.W. Howarth and S. Bringezu (Editors). Proceedings of the Scientific Committee on Problems of the Environment (SCOPE) International Biofuels Project Rapid Assessment. September 22–25. Gummersbach Germany. Cornell University, Ithaca NY. Page 1–13.

IEA. 2002. "Sustainable Production of Woody Biomass for Energy." Position paper prepared for IEA Bioenergy, International Energy Agency, Paris, France.

Kaparaju, P., Serrano, M., Thomsen, A.B., Kongjan, P. and Angelidaki, I. 2009. *Bioethanol, Biohydrogen and Biogas Production from Wheat Straw in a Biorefinery Concept*. Bioresource Technology, 100: 2562–2568.

Kojima, M. and Johnson, T. 2005. "Potential for Biofuels for Transport in Developing Countries." World Bank, Washington, DC. October.

Krohn, B.J. and Fripp, M. 2012. *A Life Cycle Assessment of Biodiesel Derived from the Niche-Filling Energy Crop Camelina in the USA*. Applied Energy, 92: 92–98.

Kumar, S., Singh, J., Nanoti, S.M., Garg, M.O. 2012. *A Comprehensive Life Cycle Assessment (LCA) Of Jatropha Biodiesel Production in India.* Bioresource Technology, 110: 723–729.

Larson E.D. 2005. "Liquid Biofuel Systems for the Transport Sector: A Background Paper." Draft for discussion at the Global Environment Facility Scientific and Technical Advisory Panel Workshop on Liquid Biofuels, New Delhi. August 29-September 1.

Leenus Jesu Martin, M., Edwin Geo, V., Prithviraj, D. 2011. *Effect of Diesel Addition on the Performance of a Cottonseed Oil Fuelled DI Diesel Engine*. International Journal of Energy and Environment. 2(2): 321–330.

Matthew, E. 2005. Palm Oil is Killing Off ohe Orangutan. http://www.Scotsman.com accessed September 24, 2012.

Machado-Filho, H. 2008. *Climate Change and the International Trade of Biofuels*. The Climate and Carbon Law Review, 2: 67–77.

Meyer, S., Schmidhuber, J. and Barreiro-Hurlé, J. 2013. "Global Biofuel Trade: How Uncoordinated Biofuel Policy Fuels Resource Use and GHG Emissions." Issue Paper No. 48. International Centre for Trade and Sustainable Development (ICTSD), Geneva, Switzerland.

Msangi, S., Sulser, T., Rosegrant, M., Valmonte-Santos, R. and Ringler, C. 2008. "Global Scenarios for Biofuels: Impacts and Implications." Biofuels and Global Food Balance, International Food Policy Research Institute, Washington, DC.

Nastari, P.M. 2005. Ethanol: The Global Overview. Presentation to the International Ethanol Conference, Brisbane, Australia. May 9–10. www.sdi.qld.gov.au/dsdweb/v3/documents/objdirctrled/pdf/11584.pdf accessed September 24 2012.

ORNL. 2012. "Popular Poplars: Trees for Many Purposes. Development Program Fact Sheet." Oakridge National Laboratory, Oak Ridge, Tennessee. http://bioenergy.ornl.gov/misc/poplars.html accessed 17 April 2011

Perlack, R.D. et al 1995. "Biomass Fuel from Woody Crops for Electric Power Generation." Report ORNL-6871. Oakridge National Laboratory, Oak Ridge, Tennessee.

Pimentel, D. and Patzek T. 2005. *Ethanol Production Using Corn, Switchgrass and Wood*; *Biodiesel Production Using Soybean and Sunflower.* National Resources Research, 14(1): 65–76.

Powlson, D.S., Riche A.B. and Shield, I. 2005. *Biofuels and Other Approaches for Decreasing Fossil Fuel Emissions from Agriculture.* Annals of Applied Biology, 14(1): 65–76.

Quirin, M., Gartner, S.O., Pehnt, M. and Reinhardt, G.A. 2004. "CO_2 Mitigation through Biofuels for the Transport Sector: Status and Perspectives, Main Report." Heidelberg, Institute for Energy and Environmental Research, Heidelberg, Germany. August.

Rohter, L. 2005. *A Record Amazon Drought and Fear of Wider Ills.* New York Times. December 11.

Rosillo-Calle, F., de Groot, P., Hemstock, S.L. and Woods, J. 2007 *The Biomass Assessment Handbook, Bioenergy for a Sustainable Environment.* Earthscan, London, United Kingdom.

Roy, P., Orikasa, T., Tokuyasu, K., Nakamura, N. and Shiina, T. 2012. *Evaluation of the Life Cycle of Bioethanol Produced from Rice Straw.* Bioresource Technology, 110: 239–244.

Sanz Requena, J.F., Guimaraes, A.C., Quiros Alpera, S., Relea Gangas, E., Hernandez-Navarro, S., Navas Gracia, L.M., Martin-Gil, J. and Fresneda Cuesta, H. 2011. *Life Cycle Assessment (LCA) of the Biofuel Production Process from Sunflower Oil, Rapeseed Oil and Soybean Oil.* Fuel Processing Technology, 92: 190–199.

Schiller, A. and Tolbert, V.R. 1996. "Hardwood Energy Crops and Wildlife Diversity: Investigating Potential Benefits for Breeding Birds and Small Mammals." Oak Ridge Associated Universities and Biofuels Feedstock Development Program, Oak Ridge National Laboratory, Oak Ridge, Tennessee. http://bioenergy.ornl.gov/papers/bioen96/schiler1.html, accessed July 16 2013

Science Daily. 2005. *Hybrid Grass May Prove to be Valuable Fuel Source.* Science Daily. September 9.

Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F.X., Elobeid, A. Fabiosa, J., Tokgoz, S., Hayes, D., Yu, T.H. 2008. *Use of US Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land Use Change.* Science 319: 1238–1240.

Sheehan, J., Camobreco, V., Duffield, J., Graboski, M. and Shapouri, H. 1998. "Lifecycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus." Report No. NREL/SR-580-24089 UC Category 1503. National Renewable Energy Research Laboratory, Golden Colorado.

Sheil, D., Casson, A., Meijaard, E., van Noordwijk, M., Gaskell, J., Sunderland-Groves, J., Wertz, K. and Kanninen, M. 2009. "The impacts and opportunities of oil palm in Southeast Asia – What do we know and what do we need to know?" Occasional Paper No. 51. Council to Improve Food and Outbreak response (IFO"R), Bogor, Indonesia.

Silva Lora, E.E., Escobar Palacio, J.C., Rocha, M.H., Grillo Reno, M.L., Venturini, O.J. and Almazan del Olmo, O. 2011. *Issues to Consider: Existing Tools and Constraints in Biofuels Sustainability and Assessments.* Energy, 36: 2097–2110.

Speight, J.G. 2013. Coal-Fired Power Generation Handbook. Scrivener, Salem, Massachusetts" and "Speight, J.G. 2014. The Chemistry and Technology of Petroleum 5th Edition. CRC Press, Taylor & Francis Group, Boca Raton, Florida

Tampier, M., Smith, D., Bibeau, E. and Beauchemin, P.A. 2004. "Identifying Environmentally Preferable Uses of Biomass Resources, Stage 2 Report: Lifecycle Greenhouse Gas Emissions Reduction Benefits of Selected Feedstock-to-Product Threads." Envirochem Services Inc.. Prepared for

Natural Resources Canada and National Research Council Canada, North Vancouver, British Columbia, Canada. July 19.

The Dutch Energy Agency (NOVEM) and Arthur D. Little (ADL). 1999. "Analysis and Evaluation of GAVE Chains," vol 1–3, GAVE Analysis Programme, Utrecht, Netherlands. December.

US EPA. 2013. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2011." United States Environmental Protection Agency, Washington, DC. April.

Van der Hilst, F., Lesschen J.P., van Dam, J.M.C., Verweij, P.A., Sanders, J.P.M. and Faaij, A.P.C. 2012. *Spatial Variation of Environmental Impacts of Regional Biomass Chains*. Renewable and Sustainable Energy Reviews, 16: 2053–2069.

Wang, M., Huo, H. and Arora, S. 2011. *Methods of Dealing with Co-Products of Biofuels in Life-Cycle Analysis and Consequent Results within the U.S. Context.* Energy Policy, 39: 5726–5736.

Wang, M., Saricks, C. and Santini, D. 1999. "Effects of Fuel Ethanol on Fuel-Cycle Energy and Greenhouse Gas Emissions." Report No. ANL/ESD-38. Center for Transportation Research, Energy Systems Division, Argonne National Laboratory. Argonne, Illinois. January

Wilhelm, W.W. and Cushman, J. 2003. "Implications of Using Corn Stalks as a Biofuel Source: A joint ARS and DOE project." EOS. Trans. AGU, 84(46), Fall Meet. Suppl., Abstract B51B-05.http://ars.usda.gov/research/publications/publications.htm?SEQ_NO_115=166979 accessed 23 May 2011

Wright, L.L. 1994. *Production Technology Status of Woody and Herbaceous Crops.* Biomass and Bioenergy, 6: 191–209.

3

Biofuel Policies

3.1 Introduction

The use of biofuels is growing around the world and the debate between biofuels supporters and opponents is intensifying. One of the main goals of developing the biofuels sector is sustainability. The sustainability driver is based on the three pillars of economic, social and environmental sustainability. In economic terms, biofuel production has to be cost effective and competitive. In social terms, biofuel development can create a massive new demand in the agricultural economy. In environmental terms, biofuel can minimize stress on natural ecosystems and the earth's resources and life support systems. The prospect of biofuel going 'mainstream' has many impacts for its commercial production and large scale use as a transportation fuel. Negative impacts, notably food prices rising, the destruction of wild ecosystems, competition for arable lands and water resources, eutrophication and land-grabbing by plantation developers is well documented in the literature in addition to the technical benefits espoused by the academic community for biodiesel and bioethanol (depends on which side of the divide the argument is made) in reducing climate instability.

In the simplest sense, biofuels can be sub-divided into two large categories: (1) biodiesel, a substitute for diesel fuel and (2) ethanol, a substitute for gasoline. This division is based on the key properties of the two products. On the one hand, biodiesel is produced from oil rich plants (such as rapeseed, sunflower and algae (Chapter 1) by mixing the vegetable oil (90%) with methanol (10%) (*transesterification*). On the other hand, bioethanol is produced through the fermentation of sugar from cereals (such as wheat and maize) or sugary feedstocks (such as sugarcane and sugar beet).

Supporters of biofuel development claim that domestically produced biofuels decrease fossil fuel use and reduce the nation's dependence on oil from foreign governments. Furthermore, claims are often made that the production and use of biofuels have energy, environmental and economic benefits. It is also claimed that use of ethanol and biodiesel reduce greenhouse gas emissions, thus mitigating the trend toward global warming and lowering emissions of carbon monoxide and other air pollutants (Crutzen et al., 2007). Finally, supporters say that greater reliance on biofuels increases economic activity in the United States, particularly in rural areas. Greater use of biofuels reduces the amount of money sent to foreign oil producers and increases the income of domestic biofuel producers and corn and soybean growers.

On the other hand, critics of biofuel development and use argue that these benefits are limited and may be offset by other factors. A compelling argument could be made as to the limited benefits derived from the significant level of government funding for biofuel development in contrast to the problematic environmental and social governance of international biofuel supply chains and whether or not that can be justified. Do the perceived benefits outweigh the many complex drawbacks? In addition, they must tackle climate change rhetoric by policy makers suggests that biofuel policy may be primarily driven by other concerns such as energy security. They argue that policies must address a wide range of pressing issues and not be narrowly defined if it is to realistically yield high social and environmental benefits. Some critics charge that more fossil fuel energy is consumed in the production of corn and ethanol than is contained in corn-based ethanol. Other critics concede that biofuels produce a modest amount of net energy, but they argue that corn and soybeans can only replace a limited portion of the petroleum-based fuels used in transportation (Dixon et al., 2007). Large-scale production could bring positive social impacts, however this is not automatic and is only realized through strict regulation of the entire supply chain (where the production aspect is closely intertwined with delivery of local socio-economic and environmental benefits).

Furthermore, the environmental impacts of conventional biofuels are widely disputed. The critics make a strong case that in developed countries not enough is done to address excessive car usage and to curb the appetite for transportation fuels. In fact, in terms of the environmental impact, all biofuels are not the same and not always the most secure or cheapest way to reduce greenhouse gas (greenhouse gas) emissions. Still, taking into account that over 20% of all anthropogenic greenhouse gas emissions originate in transport and their share is growing rapidly, biofuels provide an attractive way of reducing emissions fairly quickly. Any policy proposed for greenhouse gas reductions should be in line with the Kyoto protocol and have the potential to earn carbon credits. Ethanol proponents claim that ethanol reduces greenhouse gas emissions and emissions of various air pollutants such as carbon monoxide. Critics say that ethanol and other biofuels may increase greenhouse gas emissions despite the lower carbon emissions in ethanol compared with gasoline. Some critics have argued that the overall health impacts from air pollution due to ethanol are no better and perhaps worse, than from gasoline. In addition, critics charge that expanding corn production to produce more ethanol increases water pollution problems and uses valuable water supplies. Finally, critics have raised concerns about the impact of expanding corn production on sensitive wildlife habitats. Critics also say that corn-based ethanol has limited air quality benefits and adverse impacts on greenhouse gas emissions, water quality and supply and wildlife habitat. Plants do have multiple functions and uses, but are mostly valued by those whose livelihoods or life styles are closely aligned to nature. Commercial production systems tend to maximize only the best-selling product or ecosystem service, at the expense of others. Finally, critics question the economic benefits of crop-based biofuels – they cite higher food prices and negative impacts on livestock producers.

In measuring environmental impacts, it is important to consider the full life-cycle impacts of both biofuels and petroleum-based fuels when possible. It is well-known that different types of biofuels as well as different production technologies for the same biofuel can have very different energy efficiencies (UNCTAD, 2008: Speight, 2011c). When deciding which type of biofuel to grow and where, energy efficiency must be taken into consideration and weighed against greenhouse gas savings and other criteria. When the harvested biomass is entering the actual biofuel production process, there are further decisions to be made, as different technological options perform differently in terms of energy use. Given a relatively limited availability of biomass, energy efficiency assessment of the entire biofuel cycle should be an essential part of the overall assessment of the trade implications and the management of different policy alternatives (Birur and Beach, 2011).

Development of realistic policies is fundamental for the introduction and inculcation of a biofuel-based fuel economy. This chapter reviews policies around the globe and international instruments to assist in the development of an international biofuel market (UNCTAD, 2009). Certification by type of biofuel and standard is key to the implementation of any policy and is also examined (Echols, 2009). Finally, the policies that are in place to assist in the international trade of biofuels and the considerations that still need to be addressed are explored.

3.2 Regional, National and Local Policies

The declining reserves of conventional petroleum and the instability of governments in oil-producing nations (Speight, 2011a, 2011b, 2014) have encouraged many countries to advance their biofuel development plans and increase production targets. It is widely expected that the global production of biofuels will continue growing in the coming years, although at somewhat slower rates, reflecting the downturn in global economic activities in 2008, concerns about the economic and environmental sustainability of biofuels, food prices and other aspects. In the next few decades, global demand for transport fuel is expected to grow significantly, by up to 55% by 2030 compared compared to demand in 2004. This will accelerate the growth in demand for biofuels, as they are expected to make an increasing contribution to meeting future energy needs of mankind, plus the various ethical issues (WEC, 2010; Nuffield Council, 2011).

Demand for biofuels will grow all over the world, but particularly in developing countries, while the USA and Europe are expected to remain the biggest consumers of biofuels. The majority of biofuels will continue to be produced and consumed domestically, although the international trade in biofuels is also expected to increase significantly. Bioethanol produced from sugarcane will account for the major share of exports and Brazil is expected to remain the leading bioethanol exporter for the coming decades (WEC, 2010).

Besides the Americas and Europe, there are a number of other countries, mainly in Africa and Asia, which have the potential to become major producers and exporters of biofuels. On the other hand, South-East Asian countries that are producers of palm oil could develop competitive biodiesel production and export businesses. Their success, however, would to a large extent depend on the global trade policies and domestic subsidies (Harmer, 2009; Al Riffai et al., 2010; Mayer et al., 2013).

Some countries have set targets for the domestic use of biofuels, either for use as pure fuel or blended with conventional fuel. In more than ten

countries, oil companies are required to add a certain percentage of biofuels to the regular fuel they are selling. The official targets for the share of biofuels in the total road transport fuel consumption demonstrate significant variations across countries. The European Union, for example, is aiming for 10% of the total road transport demand by 2020 to be biofuels. Brazil, on the other hand, targeted to raise its production of bioethanol by 40% between 2005 and 2010.

To achieve these targets and objectives, governments offer a wide array of support measures and incentives, including special loan and grant programs, tax credits, tax penalties on refineries which are not using biofuels, road tax exemptions and others.

3.2.1 Africa

Several African countries have biofuel policies, some dating back to the 1970s (around the time of the start of the Proalcool program in Brazil). Malawi together with Kenya in the early 1980s and in response to the high oil prices caused by the Iranian oil crisis, successfully implemented sugar to bio-ethanol programs that included a 10% v/v blend of alcohol in gasoline (E10). To date, Malawi has sustained a 10% v/v alcohol blend while Kenya fell by the wayside on their gasohol program in the late 1980s (Wachira, 2009). In Malawi, the fuel prices have been pegged to gasoline with a 5% incentive or more given the volume of ethanol in the blend. The Malawi biofuels program has been sustainably integrated into the country's mainstream agriculture and economy. It is a question of developing joint long-term food and bio-energy strategies that are well resourced (nurtured and supported with good research backup). With the recent success stories emanating from Malawi on their agricultural bounty, one cannot say there is a conflict between food production and biofuels production.

In Kenya the declared policy is that biofuels will be developed in arid and semi-arid areas, which will not be in direct competition with food production. In the short term, interest has been aroused for rural based bio-diesel mini projects with the introduction of Jatropha. Such initiatives hope to have socio-economic benefits and mobilize gainful employment in semi-arid areas. The Kenyan government has repeatedly asserted that Kenya can by choice and action become a giant food producer. In the long term therefore, a bio-ethanol strategy can be incrementally developed alongside a successful sugar development program and a bio-diesel strategy can incrementally ride on vegetable oil production. Kenya's single distillery that produced ethanol from molasses in the 1980s suffered setbacks due to low government controlled retail prices, inadequate plant maintenance

and operation, resistance from local subsidiaries of multinational oil companies and unfavorable exchange rates (Karekezi and Kithyoma, 2003).

Zimbabwe used a cost plus model, offering the national oil company a 5% incentive above its ethanol production cost; although later the price was pegged to gasoline. Periodic droughts caused Zimbabwe to halt its blending during the early 1990s. Ethiopia has ambitious plans to develop biofuels to replace imported oil and to improve the security of supply, however, with reported perennial droughts and famines one would wonder whether food production should be the priority rather than biofuels.

South Africa is a leading producer of synthetic ethanol from coal and now there is a movement towards ethanol from crops (Apps, 2005). The South African government has developed a national biodiesel standard based on the EU standard EN 14214 and has enacted a fuel blending mandate of 10–20% biodiesel (D1 Oils, 2006; Herald (SA), 2012). Several other countries across Africa have enacted or are enacting initiatives to expand the production and use of biofuels, including Ghana and Benin. A few African countries, including South Africa and the Democratic Republic of Congo export ethanol to the EU under the General System of Preferences (GSP) and Everything but Arms (EBA) agreement.

Nigeria, the world largest producer of cassava, plans to use part of its major crop as an alternative to fossil fuel. The biomass energy resource base of Nigeria is estimated to be about 144 million tonnes per year. This includes wood, forage and shrubs, animal wastes and wastes arising from forestry, agricultural, municipal and industrial activities as well as aquatic biomass.

The land area of Nigeria area is approximately 79.4 million hectares of which 71.9 million hectares can be considered to be arable. This shows a high potential for the production of biomass since an estimated 94% of Nigerian households are engaged in crop farming. Nigeria's aggregate annual crop production of 93.3 million tonnes of major crop yields far more quantity of straws, chaff, leaves and other biomass materials.

The extent of arable land in Nigeria holds promise for producing energy crops. These energy crops are not edible and as such cannot affect the food chain. Nigeria also produces an estimated 285.1 million tonnes of manure from a livestock population of 245.9 million, which can yield about 3 billion cubic meter of biogas annually. This is more than 1.25 million tonnes of fossil fuel oil per annum. Other possible biomass resources include aquatic plants such as water hyacinth and municipal wastes, both of which constitute major environmental problems.

The country currently uses a 10% v/v blending standard of cassava ethanol with gasoline, though this is not compulsory. Nigeria aims to produce

cassava ethanol worth over US $150 million every year, once it establishes suitable infrastructure. This includes the construction of 15 ethanol plants with assistance from Brazil and plans to establish a US $100 million 'biofuel town' (600 hectare settlement of 1,000 bioenergy experts primarily from Nigeria, but also from other African countries and Brazil, who will work on novel technologies to improve bioenergy production) (Chege, 2007). Nigeria planned to start importing Brazilian ethanol-powered vehicles by 2010, but this has not happened.

It is possible that future policies will be designed to meet not only domestic needs but also the growing international demand for biofuels produced in Africa.

In 2007, the Government of *South Africa* released the first National Biofuels Industrial Strategy targeting a biofuels market penetration of 2% of liquid road transport fuels by the end of 2013. Contrary to the international situation, the main driver for the development of a biofuels industry in South Africa is neither the economic threat of increasing oil prices nor mitigation of greenhouse gas emissions, but the need to create a link between the country's first and second economies. Specifically, the government hopes to stimulate economic development and to alleviate poverty through the promotion of farming in areas previously neglected by the apartheid system. Before the release of this strategy, commercial sugar producers and maize farmers represented the majority of the parties looking to drive the South African biofuels industry. But, two years after its release, none of the ventures by these stakeholders have been able to inaugurate successful operations take off, mainly due to the restrictions on the type and source of feedstock as well as on the type of farmers whose participation in the industry would be subsidized (Letete and Blottnitz, 2012).

3.2.2 Asia and the Pacific

Several countries in the region have implemented policies to accelerate biofuel expansion to keep pace with higher energy demand (rapid population and economic growth). China has promoted ethanol on a pilot basis since 2001 in five cities in its central and north-eastern regions – Zhengzhou, Louyang and Nanyang in Henan Province and Harbin and Zhaodong in Heilongjiang Province (Murray, 2005). China's biofuel policy sets out an increase in biofuel targets from the present 3% (set in 2005) of renewable energy to 10% by 2020. One of the world's largest corn to ethanol plants (900 million liters per annum, 75% of production capacity) in the province of Jilin uses a series of financial instruments (such as tax breaks,

low interest loans and subsidies) to compensate for the difference in price between ethanol and gasoline.

The energy demand in India is met primarily through non-renewable sources such as coal, natural gas and oil. These will continue to play a dominant role in its energy scenario in the next few decades. Energy demand growth will escalate over the next several years since India's vehicular population is expected to grow by 10 to 12% per annum. Hence, securing a long-term supply of energy sources and prioritizing development are critical to ensuring the country's future energy requirements are met. Currently, the country is looking for alternative energy options from biofuels to meet the transportation sector's demand. To promote biofuels as an alternative energy source, the Government of India stipulated mandatory blending requirements of gasoline with biofuels, aided by policy incentives designed to facilitate optimal development and the utilization of indigenous biomass feedstocks for biofuel production.

Consequently, India began development of the National Biofuel Policy to promote the expansion of biofuel use in 2003 (Bhattacharya and Bharati, 2003). The government mandated the use of E5 blends in nine states (2003) and enacted an exemption on excise duty for ethanol (crop failures and drought have negatively impacted blending mandates due to insufficient locally produced ethanol) (Berg, 2004). The Indian National Bank for Agriculture and Rural Development has provided financing to banks for the development of wasteland, helping NGOs and research organizations spread awareness about biofuels through demonstration projects and supporting state government initiatives to cultivate non-edible biodiesel crops, such as pongamia. India has a significant potential for producing biodiesel from jatropha and pongamia and is working to expand its production and use of biofuels, particularly in poorer areas.

Weaknesses in India's national biofuel policy have negatively impacted the long-term sustainability of its jatropha-based biodiesel initiatives. Failure of Phase 1 of its National Biodiesel Mission, a demonstration phase targeting 0.4Mha of wasteland for jatropha cultivation, resulted from a lack of institutional support and the same is expected for its Phase 2 (B20 blends by 2012). Indian biofuel promotion policies have not yielded tangible results because of the unrealistic purchase price of Rs. 25 /L and little support from India's public oil marketing companies. Furthermore, due to ethanol shortages from 2004–05, the blending mandate was made optional in October 2004 and resumed in October 2006 in 20 States and 7 Union Territories in the second phase of the ethanol blended petrol program (EBPP) (Basavaraj et al., 2012). These ad hoc policy changes continued until December 2009, when the Government came out with a comprehensive National Policy on Biofuels

formulated by the Ministry of New and Renewable Energy (MNRE), calling for blending at least 20% biofuels with diesel and gasoline by 2017. Policy initiatives on taxation, subsidies and long term remunerative pricing are required for successful adoption of biodiesel as per the targets set by 2017 under the National Biofuel Policy (government incentives for the sector are required for effective adoption and to reverse the lack of confidence and help jatropha biodiesel compare favorably to petro-diesel economics). Serious bottlenecks are delaying the adoption of jatropha biodiesel. Blending levels in regard to biodiesel are intended to be recommendatory and are predicated on an expected yield of 1t of jatropha biodiesel/hectares of wasteland. It requires approximately 18.4 M ha of wasteland (some of which is occupied by landless laborers who use it for subsistence farming) used for grazing and remotely located, which is not always easily available. The Indian Government needs to develop an institutional mechanism for transferring the benefits of the carbon credits for jatropha plantations to its stakeholders in the sector.

Thailand plans to spend US $20 billion over the next four years on energy and energy conservation programs. The government plans to phase out the gasoline additive MTBE (which currently comprises 10% of gasoline blends) and replace it with ethanol. In the Philippines, government vehicles are required to use a 1% biodiesel blend (government is contemplating the passage of a 1% national biodiesel requirement that will increase to 5%). Ethanol is also mandated under the National Bioethanol Program starting at 5% (2007–2010) and increasing to 10% (2010–2017). This plan will displace 3.7 billion liters gasoline over a 10 year period.

Japan does not have any domestic production of biofuels and has only recently begun to import them. In 2007 Japan imported 8,880,000 tonnes of ethyl-t-butyl ether (ETBE). In its National Energy Strategy developed by the Ministry of Economy, Trade and Industry (METI), Japan has set targets for automotive fuel which will help achieve its overall objectives, including reduction of its dependence on petroleum in the transport sector to about 80% by 2030 (Murray, 2005).

In the short term, a target of 500 million liters (1% of projected fuel use in 2010) is proposed. The government proposed an E3 standard in 2004 as a lead in to a national E10 blend standard by 2010 (may be substituted with ethyl t-butyl ether, ETBE, blending).

Australia has supported ethanol since 2000 with a variety of tax incentives and production subsidies (lower excise rates than petroleum, production subsidies and capital grants to help cover cost of new production facilities) (Murray, 2005). The government plans to increase the use of biofuels to 350 million liters (2010) (a number which might well be surpassed

under the new action plan). As of 2006 more than 400 service stations around the country were selling ethanol and biodiesel blends.

3.2.3 Latin America

Latin America (LA) is endowed with large renewable energy sources and enjoys a combination of good soil, suitable climate, available land and low labor costs. Many countries show significant potential for the production of transport biofuels and have begun to explore its potential and formulate developmental plans. The growing biofuel market has both positive and negative economic, environmental and social impacts. Sustainability issues are impacted by agricultural structures and practices, land use competition, labor conditions, environmental aspects including greenhouse gases, national policies and strategies on biofuels and the enforcement of existing laws. Government planners continue to grapple with complex sustainability issues and devise policies, strategies and programs which strike a balance between the development needs of the country and the prevention of further destruction to the Amazon rainforest, degradation of the Cerrado, give careful consideration to the environmental and social impact of sugarcane harvesting, the displacement of indigenous communities and the food–fuel conflict. Brazil, Colombia and Argentina are the leaders with well-established biofuel markets. Markets in other countries are still nascent. Ecuador, Peru, Uruguay and Venezuela are now promoting programs of their own. Bioethanol production is concentrated in Brazil, Colombia and Paraguay. In Central America it is still in an early stage, while in Mexico and Bolivia plants are already being constructed. Colombia and Argentina have developed sizable biodiesel export markets while Brazil consumes its production domestically (feedstock for transesterification at the oil extraction facilities are mainly soybean oil in Argentina and Brazil and palm oil in Colombia). Guatemala has a small biodiesel market and Ecuador, Honduras, Paraguay and Uruguay have mandated low blends of biodiesel up to 2%, (B2) as additives in fossil diesel to improve its lubricating properties and lower its sulphur content. Blends such as B5 or B10 are proposed, although currently pure biodiesel (B100) is implemented only in dedicated fleets for demonstration purposes and by self-producers as an independent fuel supply.

With the development of biofuels led by Brazil, which started its Proalcool Fuel Alcohol Program to substitute ethanol for petrol and reduce oil imports three decades ago, the region could become something of a world power in energy resources (Osava, 2006). Latin America is experiencing tremendous biofuel growth, following the leadership and success of Brazil.

Brazil has a large-scale biofuels program, which focuses on the two most important transportation fuels: gasoline and diesel. Bioethanol productivity has shown a huge increase since the late seventies when the bioethanol Program, Proalcool, was introduced. In Brazil, approximately 55% of sugarcane is converted into ethanol and about 45% into sugar. The average ethanol yield is 90 l/ton of sugarcane and about 7500 l/ha of sugarcane plantation (Goldemberg et al., 2008a)

Brazil's programs, policies and institutional features include ethanol and biodiesel legislation, legal protections for investors, a mandatory limit on biofuel production, the marketing of products with social objectives and tax benefits at different levels of production and have brought about rapid progress in the nation's biofuels industry. Subsidies to increase sugar production, distillery construction, the government's promotion of flex-fuel vehicles and development of a distribution infrastructure have also helped. Brazil launched its national biodiesel program in 2004 to add 2% v/v biodiesel to petroleum diesel and this was not a mandatory measure. In July 2008 the National Council of Energy Policy (CNPE) adopted 3% v/v biodiesel as the compulsory blend, which was raised to 4% v/v in July 2009 (Winrock, 2009). The idea was to diversify fuel sources, which include castor oil, palm oil, soy oil and other oil-producing plants (Osava, 2006). In 1993 a law was passed requiring 22% v/v bioethanol addition to gasoline. Currently, this requirement has become flexible and requires between 20 and 25% v/v based on bioethanol availability. Biodiesel can be produced from a number of raw materials and the choice of the source is made depending on its availability and government incentives. The biodiesel program is considered a way to increase social and economic benefits for small, mainly family-owned agriculture.

Furthermore, in 2004, legislation was passed to encourage biodiesel producers to buy feedstock from family farmers and exempt any biodiesel produced by family farms from taxes (Rodrigues, 2005). The national oil company Petrobras is a major player in the development of the market through its large-scale infrastructure projects. Brazil's National Agri-Energy Plan addresses fuel ethanol, biodiesel, agro-forestry residues, cultivated energy forests and facilitates the development of the international biofuels trade (Trindade, 2005). Brazil also has a national certification scheme that encourages participation in the biofuels program through favorable credit policies and bidding processes.

At the governmental and private levels, Nigeria, Japan, Venezuela, China and India have partnered with Brazil to create frameworks to share technology and to seek assistance with the development, marketing, ethanol

trading technologies and expertise. Brazil's ultimate aim will be to develop and increase demand for its biofuels worldwide, help to guarantee reliability of global supply through its multiple memorandums of understanding (MOUs) with its many partners and enhance private sector development and participation.

Other countries in the region such as Venezuela and Columbia have enacted biofuel incentives. In Venezuela an ethanol blending mandate is in force in some regions and the government is considering a 10% v/v national blending mandate. Columbia currently requires a 10% v/v ethanol blend in cities with more than 500,000 people and Argentina, which still has no particular areas allocated specifically for biofuel production, has chosen to make biodiesel from soybeans. Mexico, Paraguay and Peru are in the process of developing biofuel initiatives (WEC, 2010). Peru, in support of its initiatives, has strengthened its legal framework to boost employment (encouraging the participation of small farmers and commercial producers in the growing of oil palm and jatropha) in its agricultural sector and to provide a viable economic alternative to illegal drug production. In addition to blending mandates of 7.8% ethanol with gasoline (started in 2010) and 2% biodiesel blend with diesel (started in 2009 and increased to 5% in 2011), this is expected to come from roughly 50,000 ha of oil palm and 40,000 ha of jatropha and castor bean.

As in many other developing countries, Mexico is approaching biofuels mainly from a social perspective. In 2007, the Government of Mexico took specific action in order to incorporate biofuels into the energy mix. They based this action on three principles: (1) an increase in energy security, (2) a boost to rural development, which faltered after the mass migration to the cities in the past two decades and (3) a reduction of negative environmental impacts, without jeopardizing food availability.

Mexico is a large automotive fuels consumer. In 2008, demand exceeded 780 thousand barrels a day of automotive gasoline as well as almost 300 thousand barrels a day of diesel. In real terms, Mexico consumes twice as much gasoline as the United Kingdom and 40% more diesel than Canada.

Despite being a large oil producer, the Mexican transport sector relies heavily on petroleum imports (WEC, 2010). Petróleos Mexicanos (PEMEX) is the only state-owned petrol company, entitled to produce, distribute and sell automotive fuels across all the country.

In February 2008, Mexico approved the *Law for the Promotion and Development of Biofuels*, which aims to create confidence and attract private investments, under a legal framework that defines the role of the State in guiding, coordinating and promoting the development of biofuels. The main objective of this law is to promote the production of raw materials

for the development of a biofuels industry, including agriculture, forest, waterweed and biotechnological processes. This should not add risk to food security and sovereignty, as established by the *Law for Sustainable Rural Development*. Finally, in order to promote and coordinate all the activities under this law, the Mexican Government has also created the Bioenergy Commission, including the Ministry of Energy, the Ministry of Agriculture, the Ministry of Environment and Natural Resources, the Ministry of the Economy and the Treasury.

Across the country, Mexico has more than 600 thousand hectares of sugarcane and approximately 60 sugar refineries, which produce nearly 5 million tonnes of sugar a year. Some of these refineries already have distilleries with output capacity of 167 thousand cubic meters (167 million liters) of bioethanol per year, including 33 thousand cubic meters (33 million liters) of anhydrous bioethanol. However, a large percentage of this production is for the pharmaceutical and the liquor industry. Furthermore, Mexico imports more than 50% of its bioethanol requirement.

During the last five years, Petróleos Mexicanos has performed a series of studies in order to assure the technical feasibility of using bioethanol in its gasoline mix. Results have shown that using bioethanol in small amounts does not significantly affect either the performance of vehicles, or the distribution systems. An important issue related to the introduction of bioethanol in Mexico is the setting of a competitive price. In this sense, the price conditions in Mexico are still far from competitive compared to more technologically advanced countries.

3.2.4 Europe

The EU had a regulatory framework to promote biofuels since the early 1990s which included production quotas for oilseed crops, exemptions from certain taxes and explicitly granted permission to grow non-food crops on set-aside lands. In 2003, the EU issued a directive that all member states should set national targets for the use of biofuels from 2% v.v (2005) to 5.75% v/v (2010). Most member states have developed national biofuel plans and several are providing substantial tax relief to promote biofuel production. Fuel tax exemptions are expected to enhance market competitiveness for biofuels (Sweden and Spain granted 100% tax relief for biofuels), however, this varies amongst EU countries, creating the need for greater harmonization. The EU has set bold targets for a 20% share in renewable energy by 2020 with at least 10% coming from the transport sector by 2020 (it appears unlikely that the 2020 target was met, since only 1.4% usage was achieved at the end of 2005).

EU countries plan to promote biomass for transportation, heating and electricity through policies that address supply, financing, research and balancing domestic production and imports. The EC intends to promote an integrated approach to reducing CO_2 emissions associated with the transportation sector including the use of biofuels, fiscal incentives, congestion avoidance, consumer information and improvement in vehicle technology. It also proposes the use of a wider range of biodiesel feedstocks and to ensure that only biofuels whose cultivation complies with minimum sustainability standards count towards EU targets. The EU also plans to maintain preferential market access to developing countries to help advance their biofuel markets.

In February 2006 the EC adopted a new and ambitious *EU Strategy for Biofuels* to boost the production and use of biofuels. Its goals are (1) to promote the use of biofuels in both the EU and developing countries; (2) to prepare for the large-scale use of biofuels by improving their cost competitiveness and by increasing research into 'next generation' fuels; and (3) to support developing countries where biofuel production could stimulate sustainable economic growth (Dufey and Grieg-Gran, 2010). To realize such an ambitious strategy governments will need to stimulate demand through biofuel obligations. This may happen by examining how biofuels can best contribute to greenhouse gas emission reduction targets and directing research funding towards developing the biorefinery concept and next generation biofuels.

Austria has established mandatory targets for these fuels combined with tax exemptions while France has enacted a tendering process that sets a maximum amount of biofuels for the market with tax reductions for this amount of fuel. Slovenia, the Czech Republic, the Netherlands and Germany plan to introduce obligations and the UK is considering a trading system for biofuel certificates, as well as a blending obligation and certification system.

3.2.5 North America

The United States began to seriously pursue ethanol in response to the energy crisis of the 1970s but then interest waned with low energy prices. However, as the prices of hydrocarbons have increased, interest has resurged. In 2002 the Farm Bill was passed to promote energy efficiency and the development of clean energy from alternative fuel resources that can be produced from the agricultural sector. This could have been pursued through biorefinery development grants, biomass R&D and federal procurement for bio-based products, however, funding had been inconsistent and sometimes non-existent.

US federal biofuel incentives have focused on ethanol. The first federal biodiesel tax incentive came in 2004 as part of the Jobs Bill to help reduce the price of biodiesel to consumers. The bill also applies to ethanol, extending tax credits through to 2010 and to expanding the flexibility of these credits so that they apply to any ethanol blend fraction up to 10% v/v. Biodiesel use is also promoted in the military (June 2005). The US Navy and Marine Corps were required to operate non-tactical diesel vehicles on a 20% v/v biodiesel blend (RenewableEnergyAccess.com, 2005). Biodiesel production remains low relative to ethanol production in the US; but it is growing rapidly. The US government enacted the Energy Policy Act (EPAct) of 2005 to encourage growth in the biofuels market, including the Renewable Fuels Standard (RFS) which mandates specific targets for renewable fuel use such as the production of 28 billion liters of ethanol by 2012, tax incentives for E85 refuelling stations, biofuel tax and performance incentives and authorizations for loan guarantees, a bioenergy R&D programme and biorefinery demonstration projects. Added impetus is also provided by the Energy Independence and Security Act (EISA) of 2007, which established that the annual use of renewable fuel should reach 15 billion gallons by 2015 and 36 billion gallons by 2022 to be met primarily through next generation biofuels (cellulosic, FT, gasification, pyrolysis etc.). US ethanol production is now twice that of Brazil's and this is credited to its support policies promoting its production. US ethanol production currently benefits from a $0.45/gallon subsidy and a $0.54 duty on ethanol imports. In addition to national provisions some states have also enacted policies of their own to spur market expansion RFS laws and tax incentives. North Dakota committed US $4.6 million (2005) to facilitate ethanol production by providing a tax incentive for consumers who purchase E85, establishing an investment tax credit for ethanol and biodiesel production facilities and offering income tax credits and other benefits for biodiesel. New York State offered tax credits up to US $10,000 for alternatively fuelled vehicles, depending on fuel weight (Pataki, 2006). The state was also contemplating an initiative to make renewable fuels tax free and more widely available (Pataki, 2006). Minnesota enacted an ambitious ethanol blending mandate of 20% by 2013 and 2% biodiesel blend.

In Canada, several provinces are promoting the production and use of ethanol through subsidies, tax incentives and subsidies. Ontario has enacted a 5% blending mandate (January, 2007). Manitoba and Saskatchewan have also mandated the blending of ethanol into gasoline. Canada has the bold plan to replace 35% of its gasoline with E10 blends to meet commitments under the Kyoto Protocol (requiring the production of 1.2 billion liters of ethanol) (Natural Resources Canada, 2003).

3.3 International Environmental Instruments

A major driver for biofuels is concern about climate change as well as the 2005 entry of the Kyoto Protocol. The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties by setting internationally binding emission reduction targets. Recognizing that developed countries are principally responsible for the current high levels of greenhouse gas emissions in the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on developed nations under the principle of *common but differentiated responsibilities*.

The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and began enforcement on 16 February 2005. The detailed rules for the implementation of the Protocol were adopted at the Seventh Session of the Conference of the Parties (COP 7) in Marrakesh, Morocco, in 2001 and are referred to as the *Marrakesh Accords*. The first commitment period started in 2008 and ended in 2012.

The EC is pursuing alternative fuels and vehicle technology to achieve its carbon dioxide emissions reduction targets under the international agreement. India and China, with their burgeoning middle class populations, could soon become the largest emitters of greenhouse gases; biofuels may provide a sustainable route to reverse such trends. As biofuels become a mainstream fuel, considerations such as environmental and human health regulations, development of markets for energy crops (support to the domestic agricultural sector) and international commitments on climate change will engage policy makers.

Under the Kyoto Protocol, there are two *flexible* financing provisions that could be used to promote biofuel development (1) clean development mechanism (CDM) – grants 'emissions reduction credits' for investments in emissions-reducing projects in developing countries and (2) joint implementation (JI) – grants credits for projects in transition economies. Projects must show how they plan to achieve emission reductions that are additional to any that would have occurred without such an intervention. To date there are few biofuel projects being considered because it is more difficult to determine baselines and measurement methodologies (it is difficult to determine to what extent biofuel projects will reduce greenhouse gas emissions below business as usual levels).

Europe is reforming its biofuel policy due to concerns raised about its impact on global land use change patterns and global food markets. The negative environmental impacts of the biofuels policy have been well demonstrated, but what are less clear are the economic implications.

The findings indicate that biofuel estimates of environmental, social and economic impacts show only marginal benefits at best. Therefore, there is some doubt about the wisdom of supporting biofuels in the future (Charles et al., 2013).

3.3.1 Greenhouse Gas Emissions

Furthermore, the issue of a project resulting in higher emissions elsewhere (leakage factor) can also be a problem, in spite of the complexity and burden of proof to qualify for CDM and JI grants some projects have seen the light of day in Thailand (ethanol) and India (biodiesel and ethanol). As previously discussed, biofuels can serve as a poverty eradication tool and a possible area for CDM funding is to help mitigate climate change through the expanded production and use of biofuels. Clear methodologies still need to be worked out for biofuel projects to qualify as a CDM project.

The development of carbon finance instruments and carbon markets such as the Carbon Finance Unit (CFU) of the World Bank, the Chicago Climate Exchange and the European Union's Emissions Trading System (EU-ETS) could create a market for carbon credits/emissions trading and facilitate biofuel market expansion as investors and countries seek to shift to low carbon technologies and activities to reduce greenhouse gas emissions. The effectiveness of such instruments, the robustness of carbon markets and the extent to which they will facilitate investments in sustainable emissions reducing projects such as biofuels remains unclear. Key issues will be the price of carbon, how many carbon credits will be given to biofuels and how the metrics will be determined and agreed upon.

The World Bank Carbon Finance Unit uses funds contributed by companies and countries in the developed world to purchase project-based greenhouse gas emissions reductions in developing countries and countries in transition through its eight carbon fund offerings (within the framework of the Kyoto Protocol's CDM or JI). The selling of emissions reductions or carbon finance has been shown to increase the economic feasibility of projects by adding additional revenue streams, which reduces the risk associated with lending (and by providing a means of leveraging new private and public investments into projects that reduce greenhouse gas emissions, mitigate climate change and contribute to sustainability).

Finally, the greenhouse gas emissions benefit of ethanol varies according to the feedstock used to produce it, with the greatest benefit achieved by ethanol produced from switchgrass. The negative emissions of switchgrass indicate a net sequestration of carbon into the soil and biomass. Life cycle emissions levels of biodiesel also vary according to feedstock, with

biodiesel produced from waste grease resulting in a greater greenhouse gas emissions benefit than emissions from biodiesel produced from soybean biodiesel (US DOE, 2013).

3.3.2 Other Emissions

The argument swings back and forth on the use of biofuels and emissions reduction. However, as is the case with greenhouse gas emissions, the type and amount of emissions will vary with the feedstock used to produce the biofuel.

Typically, it is believed that, compared to conventional diesel fuel, the use of biodiesel results in an overall reduction of smog-forming emissions from particulate matter, unburned hydrocarbons and carbon monoxide, as shown at right. Biodiesel slightly increases nitrogen oxide emissions, by about 2% v/v in a B20 blend. Sulfur oxides and sulfates, which are major components of acid rain, are not present in biodiesel.

As for ethanol, the oxygen atom in the ethanol molecule leads to more complete fuel combustion and generally fewer emissions. E10 blends have been credited with reducing emissions of carbon monoxide by as much as 30% and particulates by 50%. However, mixing low levels of ethanol (2% to 10% v/v) with gasoline increases the blend's tendency to evaporate and contribute to low-level ozone unless the gasoline itself is adjusted. This problem diminishes with higher levels of ethanol. At blends between 25% and 45%, the fuel is equivalent to gasoline and at higher blends it is less evaporative. E85 has about half the volatility (tendency to evaporate) of gasoline.

The effect of E85 on air quality is almost uniformly positive, with the exception of increased emissions of aldehydes, such as acetaldehyde. Conventional catalytic converters control these emissions in ethanol blends of up to 23% v/v and it is expected that they could be readily adapted to E85 blends.

A test of advanced emission control systems in three conventional gasoline vehicles found that advanced systems reduced formaldehyde emissions by an average of 85% and acetaldehyde by an average of 58%. Even without advanced controls, the benefits of reducing other toxic emissions outweigh the effects of aldehydes. The National Renewable Energy Laboratory tested a 1998 Ford Taurus – a flexible fuel vehicle (FFV) running on E85 and reported: "Emissions of total potency weighted toxics (including benzene, 1,3-butadiene, formaldehyde and acetaldehyde) for the Ford Taurus (a flex fuel vehicle) tested on E85 were 55% lower than that of the flexible fuel vehicle tested on gasoline (EFC, 2007).

3.4 Standards and Certification Schemes

As biofuels gain market share and international trading of biomass, raw materials and biofuels expands, the need to ensure socio-economic sustainability along the whole supply chain becomes more pressing. This includes aspects such as land use, agricultural practices and competition with food, energy efficiency, greenhouse gas emissions and life cycle analysis (LCA). Sustainability of a given biofuel needs to be guaranteed in a transparent way. This is only possible if appropriate policy measures influencing and steering the overall supply chain are adopted. A strategy to achieve sustainability includes the need for certification systems and systems for verifying the origin of sustainable biofuels.

Thus, as biofuel production and international trade of biomass and biofuels increases, the industrialized countries will require assurances that quality, sustainability standards and certification systems are instituted in emerging producer countries to ensure compliance with sound social and environmental practice for the growing of biomass and production of biofuels (zero harm to the environment, zero harm to people – if such a thing exists). Two of the most pressing concerns are the destruction of wild ecosystems and the competition with food uses. While international trade in biofuels is small, the call for safeguards is growing: in the EU activist and consumer groups express their concerns about the negative impacts of oil palm plantations on forests and wildlife in Indonesia and Malaysia, driven in part by the growing biodiesel demand in the EU.

Most of the standards and certification initiatives at this time are voluntary and may involve private-sector business-to-business schemes. These could be promoted by non-governmental bodies or undertaken by governments and private interests, which are implemented in connection with positive labels and intended to reward performance beyond the norm through higher prices that are expected to be paid by concerned consumers. These may be viewed as opportunities for product differentiation regarding how the biofuels are produced and their impact throughout their life cycle (promoted as a source of competitive advantage). Other regulation initiatives may be linked to tax exemptions, subsidies or other policy instruments which make eligibility dependent on certification at some stage in the biofuel production chain.

Some governments intend to have mandatory schemes to ensure that biofuels are produced responsibly and sustainably; this is important for countries who are actively trying to reduce greenhouse gas emissions under the Kyoto Protocol agreement and have included biofuels in their emission reduction plans. National policies can act as an alternative to international

certification schemes and technical assistance from industrialized nations could assist developing countries in managing their biofuel industry in a sustainable manner. Clearly, for the large-scale international biofuel trade to have a future, it must be established on the environmentally sustainable production of biomass resources supported by clear development criteria and a certification scheme that is equitable to all the stakeholders in the biofuels value chain.

Currently, a number of sustainability standards and certification schemes exist or are under development; however, no such system exists specifically for biofuels. With the proliferation of different standards (such as technical, environmental and social sustainability) by the EC, EU governments, private sector, round tables and non-governmental organizations, the risk to developing producer countries in the short term will be compliance with a plethora of schemes as they grapple with the complex issues and challenges confronting their nascent biofuel programs. A multitude of different and partially incompatible systems may arise that could lead to irreconcilable differences, lack of harmonization, incompatibility and a wastage of resources (if too many schemes in operation all at once making too many demands on scarce resources), each including a different set of requirements for compliance. Participation of both industrialized and developing countries with clear rules for mutual recognition needs to be established for harmonization and fair trading practices.

Standards would aim to address the environmental and social concerns associated with feedstocks especially when grown on a large scale and associated biofuels. From an environmental perspective mono-cropping, damage to air, water and soil by the application of fertilizers and pesticides, soil erosion, nutrient leaching, increased consumption of freshwater, loss of biodiversity and wild habitat destruction are discussed elsewhere in this book (Chapter 2 Environmental Impacts, Section 2.5 Impact of Growing Biomass). The social impacts include the effect on agricultural and rural incomes, access to markets for small farmers and their negotiating power, job availability and quality (depends on the level of mechanization, local conditions), potential for child labor, access to education and healthcare. Establishing sustainability standards and certification will go a long way to remove the negative stigma associated with large-scale biomass production and help to promote a sustainable biofuel trade.

First generation biofuel feedstocks as sugar, starch and plant oils are produced primarily from traditional agricultural crops; since they are not consumed as food and are used instead as fuel, they will have a different significance to consumers. The rapid scaling up of biofuel production is making certification an important first step towards establishing a verifiable

and sustainable biofuels industry by setting standards for cultivation and harvesting biomass. As the industry matures, more advanced and innovative certification schemes will be developed to keep pace with volume and complexity.

The response of the EU has been to ask for safeguards from exporting countries to meet minimum labor, environmental and other standards on par with their own. Some developing countries have expressed concern that rigorous certification schemes will create trade barriers that industrialized countries may use to protect their own biofuel industry (this raises the question of who will set the standards? Who will accredit the certifiers? Who will enforce regulations?). It is critical to establish standards that both exporting and importing countries agree to and ensure that these standards are applied consistently and transparently. Developing countries may in fact perform better than many industrialized countries on a range of sustainability criteria, including the greenhouse gas balance and fossil energy input, because they tend to experience higher crop yields and use fewer chemical inputs. Sustainability standards must apply equally for domestic production and biofuels traded internationally (it is important to avoid creating a double standard between importing and exporting nations).

The challenges faced by regulators in developing and implementing standards and certification schemes are highly complex and will engage policy makers for many years in heated debate as how this could be done equitably; however, trade in biomass and biofuels must try to achieve sustainable demand for the services of rural communities, provide income and employment in exporting countries, contribute to the sustainable management of natural resources, fulfill greenhouse gas emissions reduction targets in a cost effective manner and diversify the world's fuel mix away from petroleum. Some are of the opinion that environmental and social safeguards could become trade barriers and disadvantage countries who wish to enter the biofuels export market.

A compromise must be struck between developing certification schemes that are amendable, sustainable and equitable to all stakeholders – if such a thing is at all possible given the complexity of the environmental, global and social challenges. Criteria related to environmental and social issues in biofuel-producing developing countries must be appropriate to local environmental and technological conditions (commercial aims, rainforest protection, acceptance of genetically modified crops or preventing child labor) or they could be deemed too stringent and unfair and lead to compliance difficulties (too complex) or on the other hand, standards that are so watered down they are meaningless. The incremental development of standards, and by extension certification, must allow for gradual learning

and expansion with an emphasis on the continuous improvement of sustainability benchmarks.

The arguments are complex and diverse and the experts are undecided on whether certification schemes will promote or hurt trade. It is too early to make sound judgments. In the absence of legally binding legislation and with the sustainability debate ongoing in terms of competition with food, greenhouse gas emission reductions, impacts on biodiversity and rural development and voluntary standards will have to suffice in the short-to medium-term. Such standards will have an impact, depending on the share of the market they cover, the way they are implemented and their complexity; however, it is too early to tell their effects.

Certification schemes need be thorough, comprehensive and reliable and not create significant hurdles for the industry. Criteria and indicators must be carefully developed and implemented for each country or region, always mindful of cost. Monitoring and certification costs for biomass produced could erode economic competitiveness for small farmers in developing countries and as such, schemes must also be bundled with technical assistance, incentives and financing so small and medium scale producers can also qualify. It has been estimated that production costs for Brazilian ethanol may increase to 36% and eucalyptus wood chips to 42% due to strict environmental criteria (Smeets et al., 2008). Policy makers must also be mindful of sustainability and guard against possible leakage effects, through which benefits gained in one location could 'leak away' when damage occurs in another. In moving forward it will probably be necessary to establish an independent international certification body comprising stakeholders from the biomass-for-energy production chain. Public information and support will be crucial at all stages of the development process.

Technical standards (physical and chemical properties) for biofuels are also important consideration and will impact international trade (safety of fuels and protection of consumers from making purchases that could damage their vehicles' engines)**.** Two such important considerations are (1) the maximum percentages of bioethanol or biodiesel which can be mixed with petroleum fuels in the blends commercially available and (2) regulations pertaining to the technical characteristics of the biofuels themselves. Despite modest differences amongst the technical specifications for bioethanol the ASTM (American Society for Testing and Materials), ABNT (Associação Brasileira de Normas Técnicas) and CEN (European Committee for Standardization) have agreed that this does not pose a problem (bioethanol is a single chemical compound and independent of the feedstock from which is was produced).

Biodiesel however, is more problematic and requires further rationalizing and reconciling due to the fact it is not a single chemical entity and derived from several types of feedstock that can translate to variations in its chemical composition (*e.g.* different chain lengths, varying number of double bonds), which affects its performance characteristics. For example, biodiesel containing low concentrations of saturated fatty acids is less prone to fuel gelling and more suited to colder climates, as opposed to those containing a high concentration of saturated fatty acids which can cause problems in vehicle start up and operation. It is proposed that through blending, differences can be dealt with to create an end-product that meets specifications for fuel quality and emissions. The United States and Europe have developed the biofuel standards ASTM D6751 and EN 14214, respectively.

Some experts have argued that considering only purely technical specifications severely limits the type of vegetable oils and by extension range of feedstocks from which biodiesel could be produced. The DIN EU biodiesel standard 14214 has shown this trend by fixing maximum iodine levels (it is argued to be more suited to the cooler European climate) in vegetable oils used for biodiesel production, favoring homegrown rapeseed and limiting soy and palm oil, to an extent. Industrialized countries must be reasonable in setting standards for developing countries which may lack the technology and capital to produce bioethanol or biodiesel to such exacting standards.

3.5 International Trade

Currently, many countries are establishing goals for substituting biofuels for fossil fuels – although opportunities exist there are still barriers to international trade in biofuels (Junginger et al., 2010). These goals usually foresee 5 to 10% substitution while today's production, in most countries, is far below 2%. Evidently, many countries will seek to meet their ambitious biofuel targets through imports. This global trade in biofuels, which is to some extent already taking place, will have a major impact not only on other commodity markets like vegetable oils or animal fodder but also on the global land use change and on environmental impacts. The relationship between trading, policy making and sustainability impacts of biofuels demonstrates the strong but complex link between biofuel production and the global food market. Policy measures are the main drivers for production and the use of biofuels and they analyze various sustainability indicators and certification schemes for biofuels with respect to minimizing the adverse effects of biofuels while maximizing the benefits of the future use of biofuels.

However, although the international trade in biofuels is relatively small (Table 3.1, Table 3.2) it is set to increase in the coming decade as governments and industry promote the benefits and greater use of RE sources. Thus, interest in biomass resources, many of which are underutilized, is likely to foster new trading relationships. The key drivers will continue to be volatility in international crude oil prices, strong global policies on reductions in greenhouse gas emissions, increased use of biomass for CHP, rural development and liquid biofuels becoming mainstream transportation fuels. The large markets for biofuels will be the industrialized countries and major production is expected to come from sub-Saharan Africa, East Asia, Eastern Europe and the tropical countries of South America (Hoogwijk et al, 2003; FAPRI 2009).

Table 3.1 Ethanol Trade (2008).

Net Exporters	(× 1000 liters)	Net Importers	(× 1000 liters)
Brazil	4410	US	1651
China	197	EU	1100–1204
		Canada	625
		Japan	564
		ROW	563

Source: FAPRI (2009), USDA FAS (2011)

Table 3.2 Biodiesel Trade (2008).

Net Exporters	(× 1000 liters)	Net Importers	(× 1000 liters)
Argentina	999.42	EU**	1135.71–2020
Brazil*	3.78	Japan	15.14
Indonesia	386.14	ROW	1760.35
Malaysia	193.07		
US	1336.35		

Source: FAPRI (2009), USDA FAS (2011)
* Brazil (a major producer) does not export biodiesel in any significant quantities because of its domestic blending mandate (3% of its biodiesel must be included in its diesel pool) (Taylor, 2009).
**The EU is the largest producer, importer and consumer of biodiesel (USDA FAS, 2011)

As biofuels compete to substitute petro-fuels as a viable and economical alternative and governments aim to make biofuel programs mainstream and integrate them into their energy mixes, demand is expected to grow and regional feedstock in many parts of the world may prove insufficient, prompting decisions to trade biofuels internationally. This decision must be balanced with domestic and regional energy needs (exports should not pre-empt biofuel production for local use and Brazil has taken the lead on this where 3% of its biodiesel must be included in its diesel pool). Brazilian ethanol is now exported to Japan, the EU and the US; Malaysia exports palm oil to the EU. Canada exports wood pellets to Sweden, Netherlands and Belgium for residential heating systems (heating single houses), medium-scale district heating and CHP systems, in addition to co-firing in large-scale coal power plants. This is happening despite the bulky and low calorific value of biomass raw material.

Only about 10% of ethanol production is internationally traded (Hunt et al. 2006), mostly for non-transportation uses (such as alcoholic beverages and solvents). Brazilian fuel ethanol accounts for the vast majority of liquid RE traded internationally, other producers include Pakistan, the US, South Africa, Ukraine, countries in Central America and the Caribbean (relative to Brazil their exports are small). Most of the ethanol traded is manufactured in the country where the feedstock is grown (since it is not economical to transport long distances) although some corn from the US is transported to Canada; as the market develops this is expected to change. As sugarcane is the cheapest feedstock for ethanol production, many low cost producers in Africa, Latin America and Asia plan to engage in the global ethanol trade. Emerging nations must be willing to confront the challenges of import tariffs, sustainability criteria, logistics and technical standards if they are to take advantage of supply opportunities in industrialized countries.

The demand for ethanol will be driven by those countries who wish to reduce their dependence on foreign oil (greater energy independence), show strong environmental stewardship in the fight against rising climate instability (greenhouse gas emissions and worsening local and global pollution levels), boost rural incomes and support environmentally and socially responsible fuel production in developing countries. Japan, the 4th largest importer of Brazilian ethanol, has partnered with Petrobras to form a trading company to facilitate ethanol imports to Japan. In turn, Petrobras is upgrading its export terminal infrastructure at home to accommodate shipments of 25 million liters per month; it is expected other countries will capitalize on similar joint ventures to facilitate growth in the ethanol trade.

At present there is no significant international trade in biodiesel, the output from Germany, the world's largest producer is consumed domestically and within the EU. This leaves considerable potential for emerging producers to fill the gaps, including major oilseed producing countries. Soybean and oil palm account for 85% of global oil seed exports (Earley et al., 2005). The largest soybean producer and exporter is the US, followed by Brazil, Argentina and China and the largest palm oil producers are Malaysia and Indonesia which have plans to export to the EU. Malaysia also plans to export to Columbia, India, South Korea and Turkey and satisfy domestic consumption; three plants are under construction and expected to produce 100,000 tonnes per annum. Ecuador plans to export 100 million liters of palm based biodiesel to the US. Expanding palm oil plantations has been blamed for the destruction of wild ecosystems and environmental degradation in producer countries (Chapter 2, Section 2.5 Impact of Growing Biomass). Europe currently manufactures over 90% of the world's biodiesel, however the US, Ecuador, Malaysia and Indonesia are developing their supply infrastructure so the balance in production capacity is expected to shift.

For developing countries, exporting biofuels appears to be a promising proposition (rural development lower land costs, tropical climate and a longer growing season) when compared to industrialized societies. Sugarcane ethanol from Brazil, Pakistan, Swaziland and Zimbabwe is cost competitive with gasoline and is exported to the EU for blending. Some developing countries (such as Malaysia, Indonesia and the Philippines) having learned from their domestic programs and are contemplating international trade. Brazil, Germany and the US, with their fairly well developed biofuel programs and advanced technologies, are well poised to be solution providers to the market. Biofuel holds promise for those countries that promote its use in place of costly oil imports, produce it cost effectively, promote economic and rural development through the production of biomass and balance its environmental impact (Chapter 2, Section 2.5, Impact of Growing Biomass).

As the energy requirements for developing countries grow (population expansion), this should be offset by their home grown biofuel programs (use locally and export only the excess); market forces should not have the final say. For example, Brazil is planning to increase its ethanol production over the next eight years and start biodiesel production from soybeans, castor and palm oils where only a fraction of this will be exported; shoring up demands at home takes precedence over export. Exporters will have to weigh the cost of petroleum fuels versus plant oils and ethanol as well as government incentives for biofuel production, bearing in mind though

that international competition will force local producers to be more competitive in the long run.

Countries with large agricultural sectors have shown unwillingness to open their markets to biofuel imports from other countries who wish to significantly expand their production and exports. Tariffs and subsidies (which support industrialized country biofuel producers) are usually applied to keep developing country commodities out of industrialized markets. For example, in France, tax exemptions on locally produced biofuels place producers from other EU and countries outside of the EU at a competitive disadvantage. In the US, grants, tax credits and loans are provided to build the infrastructure needed for the storing, distribution and retailing of biofuels. Government procurement also gives preference to homegrown biofuels (Koplow, 2009). Almost all production stages of biofuels are subsidized in the US and in many locations producers tap into multiple subsidies at once. In fact, it has been reported that several US states provide their own volumetric subsidies to support in-state production of bioethanol or biodiesel at rates equivalent to € 0.04 per liter or more. In a few cases, these subsidies are contingent on the use of feedstock produced in the same state (in addition to federal subsidies) (Steenblik, 2007).

Some industrialized countries have granted preferential access or negotiated special trade agreements for biofuel imports to access their markets; the aim is to encourage economic prosperity in producer countries and to benefit domestic customers. The large agricultural exporting economies of the EU, the United States and Australia have imposed import duties and other restrictions on foreign ethanol and biodiesel. Simultaneously, the US and EU have also offered preferential market access to developing countries by way of tariff reductions to encourage imports. Tariff levels imposed on developing countries will largely determine the success of their nascent biofuel industries (~60% of ethanol imported into EU was done so tariff free); similarly agricultural subsidies will have an effect on the quantity and type of feedstock for biofuels production.

If industrialized countries shift traditional agricultural subsidies to domestic energy crop production, emerging developing country producers will find it difficult to compete. It is proposed that such subsidies be channeled to R&D for next generation feedstocks to give emerging producers an opportunity to remain competitive, at least in the short term. Periodically, subsidies should be revisited and revised downwards as products become more cost competitive and the funding freed up channeled to new technologies in early phases of R&D.

The primary social and environmental harms discussed negatively regarding biodiesel production globally are the growing competition for land (displacing food crops from arable lands to grow fuel instead), the ecological impact of large scale mono-cropping, genetically modified biofuel crops, the exploitation of farm workers and the lower environmental and labor standards in developing countries (could probably be addressed through standards and certification, schemes). Like any internationally traded commodity, biofuels will have a greater impact the more widely they are traded and effective national policies will be of critical importance to ensure fair trading practices.

Experts are of the view that the biofuel trade will develop into a real 'commodity market' that secures supply and demand in a sustainable way and supports price elasticity (important for long term security). Tariffs, subsidies, social and environmental obstacles, the lack of infrastructure for biofuels to be used in vehicles and unreliable supplies that can impact the market dynamic discourage long term investment (considered too risky by many investors) and impede biofuel development. Further challenges could come from competition with petro-fuels, insufficient and inconsistent support policies in both consumer and producer countries (lack of harmonization at many levels) and immature and unstable markets (too risky for long term or large volume contracts).

First generation biofuels will also be vulnerable to crop failures, market prices for food and price takers (will mirror the movement of oil prices). Although the challenges for biofuels may appear daunting, mechanisms for addressing imbalances to bring a level of comfort to the market (risk reduction) is proceeding apace and ethanol futures are now traded under the symbol *XA*. This has provided comfort to traders that price and quantity needs will be satisfied and attract new capital to the industry, ensuring transparency in trading activities and promoting market confidence.

Support policies, incentives and standards offer opportunities to formalize and stabilize the international trade in biofuels and guarantee greater overall demand. In the EU, support for biofuels through incentives for publicly and privately owned vehicle fleets (city and private bus fleets, farm and heavy goods vehicles and fishing fleets) have helped in this regard and many countries around the world have strengthened bilateral and regional cooperation to promote biofuels. While countries move to strengthen the biofuels trade, technical and logistical risks could hamper international fuel flows (transit times, cost, integration of biofuels into existing industrial and consumer transport uses) and governments must move expeditiously and purposely in addressing these important challenges.

Thus although 90% of world biofuel production is consumed domestically at the time of writing, international trade in biofuels is beginning to grow, as industrialized countries find they lack the capacity to meet growing demand and turn towards countries such as Brazil, Indonesia, or Malaysia to fill the gap. Although the increased trade levels are expected to drive the deployment of new, potentially greener fuels, there remain strong concerns that current trade regimes are not yet in place to maximize the positive contributions of biofuels or to minimize the risks. In addition, because of the concerns about the environmental impact of biofuels, many countries (particularly countries in the European Union) are moving to second-generation biofuels as a cleaner alternative and have been busy drawing up sustainability criteria that also apply to imported biofuels.

References

Al-Riffai, P., Dimaranan, B. and Laborde, D. 2010. "Global Trade and Environmental Impact Study of the EU Biofuels Mandate." Report. Specific Contract No SI2.537.787. International Food Policy Institute (IFPRI) for the Directorate General for Trade of the European Commission, Brussels, Belgium.

Apps, P. 2005. *South Africa Maize Farmers See Ethanol Plant in 18 Months*. Reuters, March 15.

ASTM D6751. 2012. *Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels*. Annual Book of Standards, ASTM International, West Conshohocken, Pennsylvania.

Basavaraj, G., Parthasarathy Rao, P., Reddy, Ch.R., Ashok Kumar, A., Srinivasa Rao, P. and Reddy, B.V.S. 2012. "A Review of the National Biofuel Policy in India: A critique of the Need to Promote Alternative Feedstocks." Working Paper Series No. 34, RP – Markets, Institutions and Policies. International Crops Research Institute, Patancheru andhra Pradesh, India.

Berg, C. 2004 "World Fuel Ethanol Analysis and Outlook." Ratzeburg, Germany, F.O. Licht, April.

Bhattacharya, P. and Bharati, J. 2003. *Strategies and Institutional Mechanisms for Large Scale Cultivation of Jatropha curcas Under Agro Forestry in the Context of the Proposed Biofuel Policy of India.* Abstract in ENVIS Bulletin on Grassland Ecosystems and Agro forestry, Indian Institute of Forest Management. Page 58–72. December.

Birur, D.K. and Beach, R.H. 2011. "Analyzing Trade Implications of US Biofuels Policies In A General Equilibrium Framework." Proceedings. Agricultural & Applied Economics Association's 2011 AAEA & NAREA Joint Annual Meeting, Pittsburgh, Pennsylvania. July 24–26.

Gerasimchuk, C.C., Bridle, I., Moerenhout, R., Asmelash, T. and Laan, E. 2013. "Biofuels – At What Cost? A Review of Costs and Benefits of EU Biofuel Policies." International Institute for Sustainable Development, Winnipeg, Manitoba, Canada. April.

Chege, K. 2007. "Biofuels: Africa's New Oil." Science and Development Network, December.

Crutzen, P.J., Mosier, A.R., Smith, K.A. and Winiwarter, W. 2007. *N2O release from Agro-Biofuel Production Negates Global Warming Reductions by Replacing Fossil Fuels.* Atmospheric Chemistry and Physics Discussions, 7: 11191–11205.

D1 Oils. 2006. The Birth of a Global Biodiesel Business. www.d1plc.com/about/history.php, accessed 15 May 2011.

Dixon, P.B., Osborne, S. and Rimmer, M.T. 2007. *The Economy-wide Effects in the United States of Replacing Crude Petroleum with Biomass.* Energy and Environment 18(6): 709–722.

Dufey, A. and Grieg-Gran, M. 2010. "Biofuels Production, Trade and Sustainable Development." International Institute for Environment and Development, London, United Kingdom.

Earley, J., Earley, T. and Straub, M. 2005. "Specific Environmental Effects of Trade Liberalization: Oilseeds." International Policy Council for Food and Agriculture, Washington, DC. October.

Echols, M.A. 2009. "Biofuels Certification and the Law of the World Trade Organization." ICTSD Program on Agricultural Trade and Sustainable Development, Issue Paper No. 19. International Centre for Trade and Sustainable Development, Geneva, Switzerland.

EFC. 2007. "The Benefits of Biofuels: Environmental and Public Health." Energy Future Coalition, United Nations Foundation, Washington, DC. http://www.energyfuturecoalition.org/biofuels/benefits_env_public_health.htm, accessed July 29, 2013.

EN 14214. 2012. Automotive Fuels – Fatty Acid Methyl Esters (FAME) for Diesel Engines: Requirements and Test Methods. European Committee for Standardization, Brussels, Belgium.

Goldemberg, J., Nigro, F., Coelho, S., 2008a. "Bioenergy in the state of Sao Paulo; Present Situation, Perspectives, Barriers and Proposal." Imprensa Oficial do Estado de Sao Paulo, Sao Paulo.

Harmer, T. 2009. "Biofuels Subsidies and the Law of the World Trade Organization. ICTSD Program on Agricultural Trade and Sustainable Development." Issue Paper No. 20. International Centre for Trade and Sustainable Development, Geneva, Switzerland.

Hoogwijk, M. et al (2003) Hoogwijk, M., Faaij, A., van den Broek, R., Berndes, G., Gielen, D. and Turkenburg, W. 2003. *Exploration of the Ranges of the Global Potential of Biomass for Energy.* Biomass and Bioenergy, 25(2): 119–133.

Hunt, S., Sawin, J. and Stair, P. 2006. "Cultivating Renewable Alternatives to Oil. In: State of the World 2006," Worldwatch Institute. W.W. Norton and Company, New York.

Junginger, M., van Dam, J., Zarrilli, S., Ali Mohamed, F., Marchal, D. and Faaij, A. 2010. *Opportunities and Barriers for International Bioenergy Trade*. Task No. 40, IEA Bioenergy, International Energy Agency, Paris, France. Also published in: Energy Policy, 2011, 39(4): 2028–2042.

Karekezi, S. and Kithyoma, 2003. 'Renewable energy technologies in sub-Saharan Africa', Presentation to Woodrow Wilson School of Public and International Affairs, Princeton University, Princeton, New Jersey. April 19.

Koplow, D.A. 2009. Boon to Bad Biofuels, Washington: Earth Track and Friends of the Earth. 2009. www.foe.org/sites/default/files/FOE%20VEETC%20Evaluation%20FINAL.pdf

Letete, T. and von Blottnitz, H. 2012. *Biofuel Policy in South Africa: A Critical Analysis*. In: Bioenergy for Sustainable Development in Africa. R. Janssen and D. Rutz (Editors). Springer, Amsterdam, Netherlands. Page 191–199.

Mayer, S., Schmidhuber, J. and Barreiro-Hurlé, J. 2013. "Global Biofuel Trade: How Uncoordinated Biofuel Policy Fuels Resource Use and GHG Emissions." Issue Paper No. 48. ICTSD Program on Agricultural Trade and Sustainable Development. International Center for Trade and Sustainable Development, Geneva, Switzerland.

Murray, D. 2005. "Ethanol's Potential: Looking Beyond Corn." Eco-Economy Update. Earth Policy Institute, Washington, DC. June 29.

Natural Resources Canada. 2003. Government of Canada Launches Ethanol Expansion Program. Government of Canada Press Release, Ottawa, Ontario, Canada. October 20.

Nuffield Council. 2011. "Biofuels: Ethical issues. Nuffield Council on Bioethics," London, United Kingdom.

Osava, M. 2006. The Time for Biofuels is Now. Energy Latin America, April.

Pataki, G. 2006. State of the State. January 4. www.ny.gov/governor/2006_sos/sos-address_text.html

RenewableEnergyAccess.com 2005.) Biodiesel Mandate for Navy and Marine Facilities. March 22.

Rodrigues, R.A. 2005. Biodiesel in Brazil – An Overview. Presentation to the Third German-Brazilian Workshop on Biodiesel, Fortaleza-Ceara, Brazil. July 1. www.ahk.org.br/inwent/palestras/rodrigo_rodrigues.ppt

Smeets, E., Junginger, M., Faaij, A., Walter, A. and Dolzan, P. 2008. *The Sustainability of Brazilian Ethanol – An Assessment of the Possibilities for Certified Production*. Biomass & Bioenergy, 32(8): 781–813.

South Africa Introduces Mandatory Ethanol Blending. 2012. The Herald (South Africa). September 3.

Speight, J.G. 2011a. *The Refinery of the Future*. Gulf Professional Publishing, Elsevier, Oxford, United Kingdom.

Speight, J.G. 2011b. *An Introduction to Petroleum Technology, Economics and Politics*. Scrivener Publishing, Salem, Massachusetts.

Speight, J.G. (Editor). 2011c. *The Biofuels Handbook*. Royal Society of Chemistry, London, United Kingdom.

Speight, J.G. 2014. *The Chemistry and Technology of Pertorleum 5th Edition*. CRC Press, Taylor & Francis Group, Boca Raton, Florida.
Steenblik, R. 2007. "Subsidies: The Distorted Economics of Biofuels. Discussion Paper No. 2007–3." The Global Subsidies Initiative (GSI), International Institute for Sustainable Development (IISD), Geneva, Switzerland. December.
Trindade, S.C. 2005a. "Global Biofuels Trade." Proceedings. XV International Symposium on Alcohol Fuels. Alcohol Fuels in Sustainable transportation: Alcohols and Other Renewable Fuels. San Diego, California. September 26–28.
Trindade, S.C. 2005b. "Brazil, The Driver of Sustainable Markets for Fuel Ethanol – Assessing the Biofuels Option." Proceedings. Global Biofuels Trade. International Energy Agency, Paris France. June 20–21.
UNCTAD. 2008. "Biofuel Production Technologies: Status, Prospects and Implications for Trade and Development." Report No. UNCTAD/DITC/TED/2007/10. United Nations Conference on Trade and Development, Geneva, Switzerland.
UNCTAD. 2009. "The Biofuels Market: Current Situation and Alternative Scenarios." Report No. UNCTAD/DITC/BCC/2009/1. United Nations Conference on Trade and Development, Geneva, Switzerland.
USDA Foreign Agricultural Service. 2011. "EU-27 Biofuels Annual Report." (GAIN Report Number NL1013). R. Flach, S. Lieberz, K. Bendz and B. Dahlbacka. The Hague, Netherlands.
US DOE. 2013. Altermative Fuels Data Center – Maps and Data. http://www.afdc.energy.gov/data/tab/all/data_set/10328, accessed July 30, 2013.
Wachira, G. 2009. *Kenya: Country Needs Sustainable Biofuel Projects*. Business Daily (Nairobi), November.
WEC. 2010. "Biofuels: Policies, Standards and Technologies." World Energy Council, London, United Kingdom.
Winrock International. 2009.Implicationsofbiofuelsustainabilitystandardsfor Brazil – CaseStudy #2,December2009. /http://www.scribd.com/doc/14532977/Winrocks-White-Paper-on-GHG-Implications-Biofuels.

4

The Biofuel Life Cycle

4.1 Introduction

Plant biomass as a source of liquid fuel for transportation (i.e. biofuels) has been widely touted as a path to national energy independence and to the mitigation of global climate change (Speight, 2008, 2011). However, the potential for the widespread adoption of biofuels to reduce net carbon dioxide (CO_2) emissions in the atmosphere has come under intense scrutiny (Tilman et al., 2006; Field et al., 2007). Future research relating to the genetics of biofuel crops and changes in nutrient cycling as a result of land conversion to biofuel crops will strongly influence the sustainability of plants as energy sources. The integration of plant science into energy industry research is crucial for the success and sustainability of biofuels. This integration will only be effective if the plant scientists and ecologists who work with biofuels can communicate new findings in a way that is useful to the larger interdisciplinary community.

Life cycle analysis (LCA) is a computational tool used to evaluate the sustainability of a future biofuel industry (Lettens et al., 2003; Malca, J. and Freire, F. 2006; Kumar and Sokhansanj, 2007; von Blottnitz, H. and Curran, M. 2007). To improve current projections of biofuel sustainability, there is

a need to reconcile the differences in methods that have thus far been used for the life cycle analysis of bioenergy (Shapouri et al., 2003; Malca and Freire, 2006.).

However, many life-cycle inventories are also incomplete, neglecting components of the production chain that are important for assessing biofuel sustainability. For example, although changes in carbon storage in soil and biomass are crucial to the outcome of greenhouse gas balances (Beeharry 2001; Dale, 2007; Fargione et al., 2008), they were not included in every life cycle assessment that estimated a greenhouse gas balance. Inclusion of plant, soil and microbial processes that determine carbon balances are limited and there is an urgent need for new research findings from plant and soil sciences to be integrated into the biofuel production chain.

Inconsistent assumptions applied to biofuel life cycle assessment lead to variable and, in some cases, conflicting results about the greenhouse gas and fossil energy mitigation potential. There have been a few attempts to standardize life cycle assessment methods but there is little consistency in the methods used (Davis et al., 2009). Differences in life cycle assessment assumptions about efficiency terms, life-cycle inventory components and system boundaries are the main factors generating variation in LCA results.

Variation in life-cycle inventories (the components used to calculate inputs and outputs) produces different life cycle assessment results and the uncertainty associated with each item in a life-cycle inventory contributes to the variation in final life cycle assessment. Although uncertain estimation is a challenge in all the fields that use complex modeling, inventory lists with component estimates and uncertainties could easily be provided in any life cycle assessment.

This chapter examines the biofuel life cycle in terms of energy and fuel characteristics. For materials such as ethanol, biodiesel, straight vegetable oils, animal fats, dimethyl ether and biomass to liquids, attributes such as energy efficiency, engine and vehicle effects and fuel consumption changes need to be addressed before use. A detailed examination of the biofuel life cycle in terms of greenhouse emissions can be found elsewhere in this book (Chapter 2: Environmental Aspects).

4.2 Energy Balance and Energy Efficiency of Biofuels

The question of energy balance is continually raised when discussing the merits or de-merits) of the use of ethanol and biodiesel as a fuel and

whether or not it requires more energy to make a gallon of ethanol or biodiesel than is contained in the biofuel itself. According to the basic laws of thermodynamics, energy cannot be created but a large portion of the energy utilized in the production of the feedstock (biomass) comes from the sun and therefore is not always included in the calculation of the net energy balance.

The production of biofuels is one of the only emerging industries where net energy balance has become such an actively-discussed controversy. The energy balance issue first arose in the mid-1970s when studies concluded that biofuel production (specifically ethanol production) was slightly energy negative (Elsayed et al., 2003). Since that time, many studies have been done and the results of these reports showed a large variation, principally due to the range of assumptions, some of which were reasonable and some of which were questionable. The importance of resolving such a debate is necessary as the technologies for biofuels develop and improve and more biofuels, which will result in the dual benefit of semi-independence or full independence from foreign oil and reduction of greenhouse gas emissions.

In terms of the energy balance, all biomass needs to go through some of the following steps: (1) growth, (2) collection, (3) drying, (4) converting to fuel and (5) being used. All of these steps require resources and an infrastructure. The total amount of *energy input* into the process compared to the energy output (energy release) by burning the resulting fuel product is known as the *ethanol fuel energy balance* (*net energy gain*) and is studied as part of the wider field of energy economics (Hill et al., 2006).

There is a variety of established and emerging biofuel technologies which use biomass to provide commercial sources of energy in the form of electricity, heat and/or transport fuels. Such biofuels can offer significant benefits, in the form of reductions in fossil fuel resource depletion and carbon dioxide and other greenhouse gas emissions which are implicated in global climate change. However, all technologies, including biofuel options, have some associated consumption of fossil fuels and emissions of greenhouse gases, directly and/or indirectly. The actual benefits which can, in practice, be realized by the use of biofuels depend, crucially, on their energy and carbon balances which indicate the magnitude of fossil fuel inputs (and related greenhouse gas emissions) relative to subsequent fossil fuel savings (and avoided greenhouse gas emissions) resulting from their use as alternatives to current commercial sources of energy.

Nevertheless, caution is advised since a considerable number of studies have been conducted for evaluating such energy and carbon balances of a range of biofuel options (Elsayed et al., 2003). These studies have been

performed in various ways to achieve diverse objectives and are presented differently. Nevertheless, these existing studies present the opportunity to formulate a consistent, coherent and comprehensive assessment and comparison of the energy and carbon balances for a range of important biofuel options in the use of biofuels.

Most important, there is an important difference between the energy balance of biofuels and petroleum fuels. The energy content (energy value, Btu/lb) in biomass feedstocks for ethanol and biodiesel are renewable, unlike the energy content in petroleum and petroleum products. The calculation of efficiency based on total energy input is therefore less meaningful for renewable fuels. A better indicator of the energy balance for biofuels is the ratio between the energy content of the fuel and the fossil energy ultimately consumed.

For a biofuel it is important to know the measure of its energy input. While biomass is photosynthesized (capture free energy of the sun), conversion to a fuel requires human effort and outside energy sources. Harvesting, transporting and refining all use energy. Some feedstocks use energy more efficiently (tropical vs. temperate sources) and some farming and refining methods are more energy efficient than others. An energy balance gives the ratio of the energy contained in the fuel to the energy input to produce it. Typically, only the fossil fuel input is considered and not the biomass input, so the term is considered the 'fossil energy balance' (an indication of biofuel ability to slow the pace of climate change). Fossil fuels generally do more harm to the environment than renewable fuels (they release sequestered greenhouse gases, sulfur, particulates, unburnt hydrocarbons, vocs, metals *etc.*) thus the more fossil fuel that goes into producing a biofuel the less desirable it is. Some approximate fossil energy balances for selected biofuels are tabulated in Table 4.1.

A biofeedstock is more productive than others. This depends upon crop productivity, the use of fertilizer, irrigation and pesticides and the energy input for harvesting and refining. Feedstocks that have high energy balances are more favorable (more energy out of the fuel as compared to the amount of fossil fuel input for its production). Sugarcane and cellulosic biomasses have a favorable energy because their residues are used to provide the process energy for their own production. Ethanol feedstocks such as sugar beets, wheat and corn are low because of the high level of fossil energy input (mechanization, fertilizers, pesticides and in the EU and the US fossil fuels are the predominant energy input).

Energy efficiency for a biofuel represents the ratio of energy in the biofuel to its total input (fossil and biomass as well as any RE inputs). This gives an indication of how much energy is lost in the conversion to fuel

Table 4.1 Energy Balance of Biofuels.

Fuel (feedstock)	Fossil energy balance (approx)
Cellulosic ethanol	2–36
Biodiesel (palm oil)	~9
Ethanol (sugarcane)	~8
Biodiesel (WVO)	5–6
Biodiesel (soybeans)	~3
Biodiesel (rapeseed, EU)	~2.5
Biodiesel (sunflower)	3
Biodiesel (castor)	~2.5
Ethanol (wheat)	~2
Ethanol (sugar beets)	~2
Ethanol (corn)	~1.5
Ethanol (sweet sorghum)	~1

Source: Extracted from Worldwatch Institute (2006)

(process efficiency). The fossil energy balance can exceed 1 (threshold considered between an energy sink and an energy source) whereas the energy efficiency cannot (some energy is lost through conversion). Tropical plants have more favorable energy ratios than those grown in temperate climates because of the longer growing season and they are cultivated manually with fewer fossil energy inputs (mechanization, fertilizers and pesticides) (Chapter 1).

However, as agricultural practices improve and conversion processes become more efficient, temperate biofuel production pathways will improve. In the near-to-medium-term the energy cost of refining biofuels from cellulosic biomass will remain above conventional feedstock (sugar, starch, plant oil), however, the benefit of cellulosic feedstock is the greater amount of residue that could be used as processing energy. The energy efficiency of carbohydrate to ethanol pathways is relatively low since fermenting sugars into ethanol entails a loss of about half the feedstock's mass and energy (released as CO_2) and fuels from cellulose are even less energy efficient because the fibers are more difficult to convert into sugars. Whereas oilseed to biodiesel pathways can be quite high, converting plant oil to biodiesel

yields an amount of fuel similar to the amount of plant oil put into the process. In the medium-to long-term the energy efficiency of biofuels is likely to compare favorably to petroleum fuels, which have higher energy efficiencies. Although unlikely, it is possible that a biofuel fossil energy balance could approach infinity if it is produced entirely from renewable energy.

The energy inputs fall into 3 main categories: *agricultural* (cultivation and harvesting), *processing energy* required to convert feedstock to fuel and *transportation* to deliver feedstock to the refinery and fuels to depots. Agricultural energy encompasses natural gas and oil used to produce fertilizers, pesticides, fuels for farms, irrigation and transport equipment. In the US, nitrogenous fertilizers make up over 70% of the energy used by farmers for growing corn. Agricultural energy input can vary widely depending upon the feedstock under consideration. For example, forestry and agricultural waste may not require any additional energy input (it is already part of the process), soybeans as nitrogen fixing plants require little or no nitrogenous fertilizer and jatropha bushes could produce reasonable oil yields in arid conditions with little fertilizer. On the harvesting side, large grain monocultures lend themselves to economies of scale and mechanized harvesting whereas in the developing world oilseeds are collected manually.

Processing energy is the energy used in converting the feedstock to fuel and can vary according to the production pathway; for example, transesterification of plant oils to biodiesel is easier than hydrolyzing and fermenting sugars to ethanol. The ethanol process may entail a hydrolysis step if starches are used and a distillation step to remove water, whereas vegetable oils can be mixed with methanol and a catalyst to produce biodiesel. Agricultural and process energy make up the bulk of energy input in biofuel production and this proportion varies based on the type of feedstock being processed into fuel (for sugar beets and wheat, the ratio is approximately 20:80, whereas for biodiesel 40:60). Transportation energy is estimated to be between 2 to 5% of biofuel energy input and makes up only a small contribution. That is because biomass feedstock, biofuel processing and consumption usually takes place within the producing country. However, as international trade expands this may be set to change (Chapter 3, Section 3.5 International Trade).

Energy efficiency in biofuel production will continue to improve as producers seek to minimize their energy costs and substitute fossil fuel with biomass residues (such as bagasse in Brazil). These initiatives will lead to improvements in the energy balance. Also, the farming of biofuel feedstock has become more efficient through improved crop yields and minimizing energy inputs and employing no-till farming (which saves energy by

reducing the need to plough) as part of better soil management practices. For example, in the US the amount of corn grown per kilogram of fertilizer has increased by 70% in the last 35 years and production of fertilizer has become more efficient. Furthermore, in the future fertilizers could well be made from syngas derived from gasifying biomass. Ethanol yields per kilogram have increased by 22% in the US since the 1970s (corn) and by about 20% in Brazil (sugarcane). This has been brought about by improvements in crushing methods and the use of enzymes. Larger production plants also bring economies of scale and justify their own combined heat and power (CHP) plants that are thermally more efficient and could be co-fired with biomass residues.

Advances in fuel conversion technologies for biorefineries, improved enzymes (lower temperatures, alcohol resistant *etc.*), use of biomass residues for fuel and utilizing other co-products are all ways to improve energy usage and exploit large amounts of raw biomass (dried distiller grain, wood wastes, corn stover, wheat stalks) for process energy. For example, Brazilian sugarcane growers could utilize leaves and tips in addition to bagasse for boiler fuel. Lignin residue, a byproduct from the conversion of lignocellulosic feedstock to fermentable sugars, can be used as boiler fuel and gasification of biomass can produce a suitable fuel gas.

Agricultural and forestry wastes could provide a rich source of process energy that requires no additional cultivation energy. They are typically collected by procedures intended to yield other products, but now mechanical harvesters that collect residue in the field simultaneously while harvesting crops are being developed. The advantage of using waste will be reflected in favorable energy balances. Perennial energy crops require less maintenance, need not be replanted each year and require less pesticides and fertilizers. Furthermore, agronomists believe they can double yields and breeders will be able to focus on growth of the entire plant. Two promising perennial energy crops, switchgrass and miscanthus, have not yet benefitted from intensive breeding and it is expected that improvements in breeding will favorably affect overall energy usage.

The debate over the energy balance and efficiency level of biodiesel fuel is continuing. Although non-food crops can be utilized to make biodiesel fuel, transitioning completely to biofuels could necessitate using huge expanses of land. Since energy consumption scales with economic output, it can be a major problem for nations with large economies. Most nations will probably not have adequate arable land to produce biodiesel fuel for the nation's requirement. Many regions may not be able to divert land away from food production but in the third world countries, biodiesel fuel sources using marginal land could make more sense. Therefore,

biodiesel fuel efficiency makes more sense in these regions. To supply the rising demand of biodiesel fuel in Europe and other markets, some tropical regions such as Malaysia and Indonesia are planting oil palm at a fast pace. The cost of producing biodiesel from palm oil offers saving over the production costs of biodiesel from rapeseed oil.

4.3 Ethanol in SI Engines

The main reason tor blending ethanol with gasoline in many countries is to reduce fossil carbon dioxide emissions (and thus the greenhouse effect) from vehicles by using bio-ethanol originating from renewable sources. Presently, gasoline sold in these countries contains 5% v/v and the relevant authorities are interested in further increasing the bio-ethanol content in gasoline. Furthermore, blending bio fuels with a petroleum-based fuel has twin advantages. Even a relatively small percentage addition will result in a substantial total volume of gasoline substitution and the present infrastructure for distributing fuels can be used largely unchanged.

Studies have also demonstrated that the octane number of a fuel can be increased by 5% for every 10% v/v ethanol added, but this can also negatively affect the heating value (Butkus and Pukalskas, 2004). For example, in Brazil, up to 25% v/v ethanol is blended in regular and premium gasoline (E25, also known as *gasohol*) and in other countries E5 and E7 are used or proposed. In addition, hydrated ethanol (E100) for dedicated ethanol and flex-fuel vehicles (FFV) are broadly used in Brazil (most fuel stations in Brazil offer both gasohol and hydrated ethanol).

E10 blends have been a successful way of making fuel ethanol mainstream; anhydrous ethanol (less than 1% v/v water) can be blended with gasoline in varying quantities up to pure ethanol (E100) and most SI engines will operate well with mixtures of 10% v/v ethanol (E10). Such blends do not require engine tuning or vehicle modifications (no substitution of parts, most of the materials used by the automotive industry over the last 2 decades are E10 compatible). Corrosion problems could be avoided through the use of suitable fuel ethanol specifications (such as the American Society for Testing and Materials and similar standards organizations), avoidance of water contamination and treatment with corrosion inhibitors as required. Ethanol (neat or blended) acts as a solvent and removes deposits from a vehicle's fuel system (previously run on gasoline or diesel) and more frequent fuel filter replacement is recommended to prevent clogging and hard starting. Spark plugs should also be cleaned more often especially during the initial phase of operation to avoid build-up of combustion chamber deposits and fouling.

Low ethanol blends do not result in perceived changes in performance or drivability and maintenance requirements do not differ from those with gasoline usage. For example E5 and E10 wheat-based ethanol have a change in fuel economy of -0.73% and -5.2% (Gnansounou et al., 2009). The variation in fuel consumption is very small and use of these blends is considered environmentally friendly (and thus well received by the public). Ethanol has a higher octane number (108), broader flammability limits, higher flame speeds and higher heats of vaporization than gasoline; benefits are higher cylinder compression ratios, shorter burn time, leaner fuel mixes (efficiency advantages in IC engines) and cleaner burn (oxygenated (35% by weight) and fewer harmful emissions); disadvantages are lower energy density (32% lower than gasoline), corrosiveness, lower vapor pressure and miscibility with water (Speight 2008).

In Brazil, automotive gasoline contains anhydrous ethanol in the range of 20 to 25% v/v (E20 to E25) and manufacturers have been customizing vehicles to run on these blends for over 25 years (ethanol compatible materials, engine tuning *etc.*). This normally results in good drivability and performance with fuel consumption comparable to gasoline operation. In the US state of Minnesota and in Australia there have been some attempts to introduce blends beyond E10 but limited to E20. Existing vehicles will have to be modified and engines tuned for trouble free operation; materials such as aluminum, magnesium, zinc, lead, brass, natural rubber, nylon and PVC may degrade after prolonged contact with ethanol. As such, engine customization for a particular blend must be evaluated before routine use. A number of major auto manufacturers now offer E20 compatible models.

E85 blends have been in use in the US since the early 1990s. More recently, in Canada and Sweden in flexible fuel vehicles (FFVs) which can operate on straight gasoline or any gasoline-ethanol blend up to E85, the technology uses sensors to measure ethanol concentration in the fuel and automatically compensate for engine tuning. For example, if no ethanol is present, the engine will self-calibrate to gasoline-only operation (these changes are undetectable by the driver). In Brazil, a variant capable of operating either within the E20 - E25 range, with E100 exclusively or with any blend of E20 - E25 and E100 was introduced. In this model, ethanol sensors were replaced with an advanced software component in the engine's electronic control unit which uses inputs from conventional oxygen sensors in the exhaust system and self-calibrates the engine to fuel requirements.

Cars with specially-designed engines (flex-fuel vehicles, FFVs) can run on any mix of gasoline and hydrous bio-ethanol. E100 flex-fuel vehicles are now the vehicle of choice in Brazil because E100 (pure ethanol) is significantly less expensive than E20 or E25 in much of the country and can

be found at more than 29,000 retail stations throughout the country. A number of the major automakers are now offering flex-fuel vehicles to meet demand. Flex fuel vehicles are built with ethanol-compatible materials, have shown proven reliability, come with manufacturer warranties and their maintenance costs are comparable to gasoline vehicles. Because of the lower energy content in ethanol, fuel consumption in E85 and E100 is higher than with gasoline or E20 or E25 and the average drop in fuel economy is between 25–30%, depending upon vehicle/engine characteristics (performance can be improved at moderate cost with existing technology). However, some fuels have a much larger drop: wheat based ethanol has a drop of 42% in fuel economy (Gnansounou et al, 2009). The price of flex fuel vehicles both in Brazil and United States has been competitive with gasoline vehicles.

Most of the dedicated ethanol vehicles are found in Brazil; equipped with fuel injection and electronic ignition, they have demonstrated proven reliability, good drivability and low maintenance costs. The USEPA through its National Vehicle and Emissions Laboratory has conducted trials with 'neat' ethanol. The study concluded that high combustion efficiencies yield up to 20% fuel economy over baseline gasoline engines (benchmark for dedicated ethanol engines).

The emissions of ethanol are considered to be less damaging to the environment compared to using conventional petrol. The use of ethanol in spark-ignition engines compared to petrol has lower emissions of carbon dioxide and unburned hydrocarbons. Furthermore, using 10% ethanol can reduce carbon monoxide emissions by up to 30%. Unfortunately, acetaldehyde and acetone emission can be up to thirteen times higher compared to gasoline, however they are considered less unfriendly to the environment compared to carbon monoxide (Butkus and Pukalskas, 2004).

The disadvantage of using ethanol in gasoline is that ethanol has a lower heat content than gasoline and can reduce the efficiency of the fuel. However this may be partly offset by the higher octane rating of ethanol (RON: 108.6) compared to the octane rating of the gasoline (RON, premium gasoline: 91–97).

4.4 Ethanol in CI Engines

Diesel exhaust is a major contributor to various types of air pollution, including particulate matter (PM), oxides of nitrogen (NOx) and carbon monoxide (CO). It has been demonstrated that the formation of these air pollutants can be significantly reduced by incorporating or blending

oxygenates into the fossil fuels matrix. Over the last two decades in the United States, Brazil and other parts of the world, oxygenates, such as methyl-tertiary-butyl ether (MTBE) and ethanol, have been recognized as key elements of cleaner burning gasoline and diesel but are limited to mainly experimental testing (Ahmed, 2001; Hira and Singh, 2012; Pandey et al., 2012). However, contrary to popular opinion, diesel engines can be run on pure alcohol. The main problem is in the lubrication of the injectors, which can be solved by the addition of 5 to 20% v/v vegetable oil (or other suitable lubricant) to the alcohol. It is also possible to make a diesel *fuel* with up to 80% alcohol. Since alcohol and oil will not mix when water is present, both the alcohol and the oil must be anhydrous. Different engines may also require adjustments of the metering pump for optimum performance. Diesel engines, especially turbocharged diesels, may also be run with an alcohol/water injection system as described later.

There has only been limited use of ethanol in CI engines *on a commercial basis* – a well-documented example is the use of ethanol in urban buses in Sweden as a way of meeting environmental requirements (reduced particulate emissions). A drop in fuel economy of 40 to 50% relative to diesel and higher maintenance costs were reported (operational performance was considered adequate). Ethanol is difficult to blend with diesel when compared to gasoline; however, the emulsion can be used in a diesel engine. Diesel-ethanol blends up to 15% v/v ethanol have been used and a good compromise (fuel economy, performance, drivability, emissions) is achieved with about 7% (loss of about 2% in fuel economy depends upon power train characteristics and in service conditions).

Diesel ethanol blends (emulsion) need to be carefully evaluated because some fuel delivery systems may be sensitive to ethanol and suffer premature wear; filters and lines need to be compatible and water contamination should be avoided to prevent phase separation (water in the combustion chamber could damage the engine). 'Fumigation' uses diesel and ethanol simultaneously without blending; here ethanol is injected directly into the engine's air intake manifold. Tests have been done injecting ethanol directly into the cylinder, showing that up to 90% diesel displacement could be achieved. Commercial success has been limited due to the complexity of this process, however, advanced onboard electronics, sensors, digital engine operation mapping, precise ethanol metering at selected engine operation modes could help to simplify the hardware, optimize the benefits of ethanol and reduce costs. Some diesel engines could even be converted to SI to enable them to run on ethanol, however, this typically requires a significant reduction in the compression ratio and is not desirable because it significantly lowers the combustion efficiency.

4.5 Biodiesel Blends

Biodiesel is a domestically produced, renewable fuel that can be manufactured from new and used vegetable oils, animal fats and recycled restaurant grease. Biodiesel's physical properties are similar to those of petroleum diesel, but the fuel significantly reduces greenhouse gas emissions and toxic air pollutants. It is a biodegradable and cleaner-burning alternative to petroleum diesel. Anyone who believes that petroleum-based diesel is a clean burning fuel should follow a diesel-fuel vehicle up a slight-to-medium incline.

Biodiesel blends are denoted as *BXX* with XX representing the percentage of biodiesel contained in the blend (i.e., B20 is 20% biodiesel, 80% petroleum-based diesel). Biodiesel can be blended and used in many different concentrations, including B100 (pure biodiesel), B20 (20% v/v biodiesel, 80% v/v petroleum diesel), B5 (5% v/v biodiesel, 95% v/v petroleum diesel) and B2 (2% v/v biodiesel, 98% v/v petroleum diesel). B20 is a common biodiesel blend in the United States (US DOE, 2008).

Biodiesel can be legally blended with petroleum diesel in any percentage and there are specifications for conventional diesel fuel (ASTM D975). These specifications allow for biodiesel concentrations of up to 5% (B5). Low-level biodiesel blends, such as B5 are approved for safe operation in any compression-ignition engine designed to be operated on petroleum diesel. This can include light-duty and heavy-duty diesel cars and trucks, tractors, boats and electrical generators.

B20 is popular because it represents a good balance of cost, emissions, cold-weather performance, materials compatibility and ability to act as a solvent. Using B20 provides substantial benefits and avoids many of the cold-weather performance and material compatibility concerns associated with B100. Most biodiesel users purchase B20 or lower blends from their petroleum distributors or biodiesel marketers. Biodiesel blends of 20% (B20) or higher qualify for biodiesel fuel use credits under the United States Energy Policy Act of 1992 (US DOE, 1992). B20 and lower-level blends generally do not require engine modifications. Engines operating on B20 have similar fuel consumption, horsepower and torque to engines running on petroleum diesel. B20 has a higher cetane number (a measure of the ignition value of diesel fuel) and higher lubricity (the ability to lubricate fuel pumps and fuel injectors) than petroleum diesel.

However, not all diesel engine manufacturers cover biodiesel use in their warranties because diesel engines are expensive. Users should consult their vehicle and engine warranty statements before using biodiesel. Biodiesel

blends between B6 and B20 must meet prescribed quality standards (ASTM D7467). Biodiesel contains about 8% less energy per gallon than petroleum diesel. For B20, this could mean a 1% to 2% difference, but most B20 users report no noticeable difference in performance or fuel economy. Greenhouse gas and air-quality benefits of biodiesel are roughly commensurate with the blend. B20 use provides about 20% of the benefit of B100 use.

B100 and other high-level biodiesel blends are less common than B5 or B20 due to a lack of regulatory incentives and pricing. B100 can be used in some engines built since 1994 with biodiesel-compatible material for parts, such as hoses and gaskets. B100 has a solvent effect and it can clean the fuel system of the vehicles and release deposits accumulated from previous petroleum diesel use. The release of these deposits may initially clog filters and require filter replacement in the first few tanks of high-level blends.

When using high-level blends, a number of issues can come into play. The higher the percentage of biodiesel above 20% v/v, the lower the energy content per gallon. High-level biodiesel blends can also impact engine warranties, gel in cold temperatures and cause microbial contamination in tanks. B100 requires special handling and may require equipment modifications. To avoid engine operational problems, B100 must meet the specified standards (ASTM D6751). Biodiesel meeting this standard is legally registered as a fuel blend stock or additive with the US Environmental Protection Agency. However, B100 does have a disadvantage insofar as use of B100 could increase nitrogen oxides emissions, although it greatly reduces other toxic emissions.

Certain technological challenges must be overcome before biodiesel wins acclaim amongst the world's major automakers. Biodiesel oxidizes much faster than ordinary diesel, so proper care is needed to avoid deterioration during storage or you can have formation of aldehydes, alcohols, shorter chain carboxylic acids, insoluble, gum and sediment. In addition, moisture may result in bacterial growth and the formation of corrosive fatty acids that impact negatively on the engine's fuel system and lead to filter plugging (additives are usually employed for long term storage). From the literature, the oxidation stability of Jatropha biodiesel has been found to increase with increasing dosages of antioxidant. It is found that a dosing of 200 ppm of antioxidant is the minimum requirement to meet EN 14112 specification for biodiesel oxidative stability (fuel grade biodiesel normally conforms to international standards EN 14214 (EU) or ASTM D 6751 (US) but other standards also exist). The presence of water in biodiesel reduces the heat of combustion and when mixed with diesel, acts as a solvent and removes deposits from the vehicles fuel system.

Biodiesel mixes with diesel at any concentration; B20 blends are common and most vehicles run with few or no modifications (hoses, seals, pumps, O-rings, fuel injector orifices etc. not affected). Kumar et al. (2012) reported a blend of 50% petro-diesel with 50% Jatropha biodiesel (B50) gave a performance comparable to that of pure diesel (D100) and a blend of 80% petro-diesel with 20% Jatropha biodiesel (B20) gave good mechanical efficiency at engine full load. Some contradictions still exist among researchers either reporting higher or lower values for thermal efficiencies brake specific fuel consumption (BSFC) and exhaust temperatures for biodiesel blends compared to mineral diesel. The brake power and torque for engines run on diesel were higher than the torque obtained using biodiesel for both naturally aspirated (NA) and turbocharger (TU) operations.

B5 blends have been reported to enhance the lubricity of low sulfur diesel fuel. Higher viscosity biodiesel blends (greater than B20) could affect fuel flow and atomization in the engine's combustion chamber especially in cold conditions. Biodiesel's high cetane number is an advantage as this has a pronounced effect on the combustion quality (emissions reduction) and mixing biodiesel with ordinary diesel raises the cetane value of the blend. Biodiesel shows up to 12% lower energy content than diesel (product characteristics depends on feedstock and manufacturing process). A loss in fuel economy and performance for B20, 0–6% and for B5 0–2% is reported (barely noticeable).

The maintenance requirement for engines operating on biodiesel blends (B20 <) shows little difference compared to those operating on ordinary diesel although modified injection timing and duration for better combustion is reported. In a long-term performance evaluation using B20, engine and fuel system components were disassembled, inspected and evaluated to compare wear characteristics after 4 years of operation (> 600,000 miles) and sludge accumulation on engine parts. No differences in wear or other issues were noted during the engine teardown. However, the cylinder heads of B20 engines contained a heavy amount of sludge (possibly caused by accumulation of soaps (contain high levels of sodium) in the engine oil) around the rocker assemblies. This was not the case in diesel engines. The B20 engines required injector nozzle replacement over the evaluation and teardown period, probably due to off-spec fuel.

4.6 Unblended Biodiesel

Biodiesels are defined as mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, which conform to the specifications for

use in diesel engines (ASTM D6751). The word *biodiesel* refers to the pure fuel before blending with diesel fuel.

Biodiesel is a clean burning alternative fuel produced from domestic, renewable resources such as vegetable oil or animal fat (Chapter 1). Biodiesel contains no petroleum, but it can be blended at any percentage with petroleum diesel to create a biodiesel blend. Biodiesel can be used in compression-ignition (diesel) engines with little or no modifications. Biodiesel is simple to use, biodegradable, nontoxic and essentially free of sulfur and aromatics. One major advantage of biodiesel is the fact that it can be used in existing engines and fuel injection equipment with little impact to operating performance. Biodiesel has a higher cetane number (measurement of ignition quality of diesel fuel) than most diesel fuel produced in the United States. Furthermore, in terms of on-road miles and numerous marine and off-road applications, biodiesel shows similar fuel consumption, horsepower, torque and haulage rates as conventional diesel fuel.

All diesel fuel injection equipment has some reliance on diesel fuel as a lubricant. The lubricating properties of diesel fuel are important, especially for rotary and distributor type fuel injection pumps. In these pumps, moving parts are lubricated by the fuel itself as it moves through the pump – not by the engine oil. Low lubricity fuel may cause high wear and scarring and high lubricity fuel may provide reduced wear and longer component life. Lubricity results of biodiesel and petroleum diesel using industry test methods indicate that there is a marked improvement in lubricity when biodiesel is added to conventional diesel fuel. Even biodiesel levels as low as 1%v/v can provide up to a 65% increase in lubricity in distillate fuels.

Users of a 20% biodiesel blend with #2 diesel will usually experience an increase of the cold flow properties (cold filter plugging point, cloud point, pour point) at approximately 2°F to 10°F. Precautions employed for petroleum diesel are needed for fueling with 20% blends. Neat (100 %) biodiesel will gel faster than petroleum diesel in cold weather operations. Solutions for winter operability with neat biodiesel are much the same as that for low-sulfur #2 diesel (i.e., blending with #1 diesel, the utilization of fuel heaters and the storage of the vehicle in or near a building). These same solutions work well with biodiesel blends, as does the use of cold flow improvement additives.

Thus, for the successful adoption and promotion of biodiesel, the most critical issues are the physical and chemical properties as compared to that of petro-diesel so that biodiesel can be used in existing engines without any major modifications. Higher cetane numbers, low sulphur, oxygen in its molecular structure (leading to better combustion), a higher

flash point, lower emissions of particulate matter (lower aromatic and short-chain paraffin HC and higher oxygen content), carbon monoxide and hydrocarbons with no noticeable increase in fuel consumption or decrease in engine performance are now accepted facts when using biodiesel. In addition, there is less carbon accumulation on cylinder heads, pistons, piston ring grooves and injectors when compared to petro-diesel.

The emission of aromatic and poly-aromatic compounds and metals, as well as their toxic and mutagenic effect, has been generally reported to be less with biodiesel as compared to diesel exhausts (emission data for biodiesel compared to petro-diesel revealed a reduction in CO_2 and SO_2 levels however inconclusive for oxygenated compounds such as aldehydes and ketones). Neat biodiesel (B100) can be used in existing diesel engines with modifications (viton fuel system components, tuning of fuel injection timing, etc.) and is better suited to warm climates. For colder climates, problems could be overcome by the installation of tank heaters and anti-gel additives. Maintenance on engines using B100 is similar to those run on diesel and it is reported that they produce lower soot deposits on injectors and in the combustion chamber; fuel filter life and oil changes could also be extended.

4.7 Other Biofuels

Biofuels are fuels that are produced from living organisms and are made from biomass (most often referring to plants or plant-derived materials) conversion. This biomass can be converted to energy in three different ways: (1) thermal conversion, (2) chemical conversion and (3) biochemical conversion (Chapter 1). The biomass conversion processes can produce solid, liquid, or gaseous fuels. The goal is for biofuels to meet more than a quarter of world demand for transportation fuels by 2050 to reduce dependence on petroleum and coal (Speight, 2011, 2008, 2013, 2014).

In the context of this chapter, it must be remembered that biodiesel, on the other hand, is a product produced from a chemical reaction between a bio-oil, methanol and a catalyst (Chapter 1). Biodiesel has substantially different properties than vegetable oil and other natural oils. This results in better engine performance. In most cases biodiesel has a lower boiling point and viscosity than natural oils do. Biodiesel has a cetane rating substantially higher than petrol diesel and it leaves minimal carbon deposits. More important, no modifications are needed for diesel engines to use biodiesel. Specifications have to be met to ensure the quality of biodiesel used in the United States (ASTM D6751).

4.7.1 Vegetable Oil and Animal Fats

Vegetable oil (new or waste) and animal fat (tallow, lard, yellow grease, chicken fat) comprise of triglycerides (byproduct from the metabolism of living creatures) which can be used as fuel in diesel engines.

The concept of using straight vegetable oil to power an engine is not new – Rudolf Diesel originally designed the diesel engine to be fueled by peanut oil. Modern diesel engines, however, are very different from the early prototypes. The advent of the injection pump, high-pressure fuel systems and various high tolerance parts require that a less viscous fuel be employed. In addition to this, straight vegetable oil is prone to polymerizing as well as coking under the extreme conditions found within a diesel engine.

Most modern diesel car engines are suitable for the use of straight vegetable oil (SVO), also commonly called pure plant oil (PPO), with suitable modifications. Principally, preheating it, typically by using waste heat from the engine or electricity, must reduce the viscosity and surface tension of the straight vegetable oil/pure plant oil. Otherwise, poor atomization, incomplete combustion and carbonization may result. One common solution is to add a heat exchanger and an additional fuel tank for the petro-diesel or biodiesel blend and to switch between this additional tank and the main tank of straight vegetable oil/pure plant oil. The engine is started on diesel, switched over to vegetable oil as soon as it is warmed up and switched back to diesel shortly before being switched off to ensure that no vegetable oil remains in the engine or fuel lines when it is started from cold again. In colder climates it is often necessary to heat the vegetable oil fuel lines and tank as it can become very viscous and even solidify.

Modifications to the engines cold start regime assist combustion on startup and during the engine warm up phase. Suitably modified indirect injection (IDI) engines have proven to be operable with 100% pure plant oil down to temperatures of -10°C. Direct injection (DI) engines generally have to be preheated with a block heater or diesel fired heater. For long term durability it has been found necessary to increase the oil change frequency and to pay increased attention to engine maintenance.

Due to the high viscosity (an order of magnitude higher than the viscosity of petro-diesel), using vegetable oil/pure plant oil in an unmodified engine will result in poor atomization because of low volatility, incomplete combustion, coking of injectors and the accumulation of soot in the combustion chamber and lube oil (Leenus et al., 2011). These disadvantages can contribute to the formation of carbon deposits, incomplete combustion and increased emissions from the engine (Leenus et al., 2011).

Modifications can be made to use straight vegetable oil, which can be used with diesel in a dual fuel mode with the necessary modifications (additional fuel tank, system for switching from diesel to straight vegetable oil, heating system). For example, in a switching system, the engine is started on diesel and then switched to straight vegetable oil and just prior to shutdown it is switched back to diesel to ensure no straight vegetable oil remains in the engine, thus avoiding hard starting. Viscosity can also be reduced by the addition of methanol, oxygenated organic compounds, diesel fuel, micro-emulsification, transesterification and preheating (Leenus et al., 2011).

Blends of vegetable oils can also minimise the problem of viscosity. For example, even though pure cottonseed oil is fifteen times more viscous than diesel, a blend of 20% cottonseed oil in diesel is only twice as viscous as diesel (Leenus et al., 2011).

When cottonseed oil is used in a compression ignition engine, emissions are comparable or better than when diesel is used. Specifically, a blend of 20% cottonseed oil in diesel has the same smoke emissions, 110% of the hydrocarbon emissions, 105% of CO emissions and 97% of the NOx emissions when compared to diesel (Leenus et al., 2011).

However, operators should be aware that use of straight vegetable oil is entirely different from the use of ASTM-grade biodiesel. Neat vegetable oils and recycled greases (also called waste cooking oil or yellow grease) that have not been processed into mono-alkyl esters are not biodiesel. These raw oils, used as fuel extenders or fuel substitutes, are not registered with US Environmental Protection Agency and are not legal to use as a motor vehicle fuel. Furthermore, cooking oil is physically and chemically different than diesel fuel and its use in conventional engines will generally cause negative effects on emissions and engine durability.

Because of the potential for increased emissions, it is considered unlawful to tamper with and convert a vehicle designed for diesel fuel to operate on waste oil without certification by the US Environmental Protection Agency. To date, the US Environmental Protection Agency has not certified any conversions for waste oils. Even with certification by the US Environmental Protection Agency, conversions may violate the terms of the vehicle warranty.

In summary, the published engineering literature strongly indicates that the use of straight vegetable oil in a diesel engine will lead to reduced engine life.

There is also favorable potential for the use of animal fat as a source of biodiesel. Animal fat-based biodiesel gained a poor reputation in the early years of the industry because some producers ignored quality standards and did not adequately manage their chemistry or downstream refining.

More recently, it has been recognized that there are many high-quality animal fat-based biodiesel producers that can be used to yield a product that meets ASTM specifications. In terms of the cetane number, animal fat-based biodiesel is between 56 and 60. In addition, animal fat-based biodiesel provides added lubricity, a measure of protective compounds in the fuel that reduce engine wear and tear. As long as the product meets ASTM standards, animal fat-based biodiesels are safe to use in all diesel engines. Most original equipment manufacturer dealers and customer service departments recommend B5 blends, while some promote B20 blends. Like other biodiesel, it acts as a solvent, releasing the deposits that build up after using petroleum-based diesel.

While all biodiesel is greener than petroleum-based diesel, animal fat-based biodiesel offers the most sustainable choice because it uses byproducts as a feedstock instead of relying on virgin materials. Without modifications or treatment, biodiesel can form sediments during storage. However, the higher percentage of saturated fats in animal fat-based biodiesel provides greater oxidative stability than its plant oil-based counterparts, reducing the risk of sedimentation.

The bottom line is that if biodiesel meets the prevalent ASTM specification, the feedstock used to produce it should not be a question. Animal fat-based biodiesel continues to measure up and to meet renewable fuel obligations, animal fats represent a promising resource.

4.7.2 Dimethyl Ether

Dimethyl ether (DME, methoxymethane, CH_3OCH_3; boiling point: -11°C, -24°F) is the simplest ether and exists as a colorless gas that is a useful precursor to other organic compounds and an aerosol propellant (Müller and Hübsch, 2005). Like liquefied petroleum gas (LPG), dimethyl ether changes to a liquid when subjected to modest pressure or cooling, which makes dimethyl ether easy to transport and store. This and other properties, including a high oxygen content, lack of sulfur or other noxious compounds and ultraclean combustion make dimethyl ether a versatile and promising solution in the mixture of clean renewable and low-carbon fuels under consideration worldwide.

Dimethyl ether is primarily produced by converting hydrocarbons sourced from natural gas or coal (or, for that matter, from any feedstock that can be gasified to produce synthesis gas) by gasification to synthesis gas (syngas), a mixture of carbon monoxide and hydrogen (Lee, 2007; Speight, 2008, 2011, 2013). Synthesis gas is then converted into methanol (CH_3OH) in the presence of catalyst (usually copper-based), with

subsequent methanol dehydration in the presence of a different catalyst (for example, silica-alumina) resulting in the production of dimethyl ether:

$$CO + 2H_2 \rightarrow CH_3OH$$

$$2CH_3OH \rightarrow CH_3OCH_3 + H_2O$$

This is a two-step (indirect synthesis) process that starts with methanol synthesis and ends with dimethyl ether synthesis (methanol dehydration). The same process can be conducted using organic waste or biomass as the starting feedstock (Speight, 2008). Alternatively, dimethyl ether can be produced through direct synthesis, using a dual catalyst system that permits both methanol synthesis and dehydration in the same process unit, with no methanol isolation and purification. By eliminating the intermediate methanol synthesis stage, the process shows higher efficiency and cost benefits. However, while both the one-step and two-step processes above are commercially available, there is more widespread application of the two-step process since it is relatively simple and start-up costs are relatively low. This may change as development and evolution of the one-step process occurs.

Dimethyl ether can be produced from a variety of biomass sources and is considered a promising substitute for diesel and LPG (interest in EU and Japan) as it can be stored in cylinders at low pressures. For vehicle use though, DME attacks sealing materials (use metal to metal, graphite, Teflon). It can be used in place of diesel; its energy density is ~80% that of diesel, its cetane number 55–60 (46–57.8 for diesel) and zero sulfur and aromatics (environmentally friendly). In CI engines it is reported to produce lower noise levels and emissions (NO_X reductions may be further improved by end of pipe abatement). Some of the major engine makers have expended resources with regard to customizing engines to run on DME (material choice, fuel injection and ignition advance). The driving range for DME (higher energy density) is expected to be higher than CNG but further testing is required to evaluate DME before definitive statements can be made. DME from biomass is still in the early stages of development, however, as interest mounts this will change.

4.7.3 Biomass to Liquid

The biomass-to-liquids (BtL) concept is a multi-step process which commences with the gasification of the biomass to ultimately produce liquid

fuels. The process uses the whole plant to improve the carbon dioxide balance and increase yield.

Gasification occurs through the thermal decomposition of biomass with the help of an oxidant such as pure oxygen or oxygen enriched air to yield a combustible gas such as synthesis gas (syngas) rich in carbon monoxide and hydrogen (Albertazzi et al., 2007). The synthesis gas is post-treated, by steam reforming or partial oxidation, to convert the hydrocarbons produced by gasification into hydrogen and carbon monoxide. The carbon monoxide is then put through the shift process to obtain a higher fraction of hydrogen, by carbon dioxide-removal and methanation or by pressure swing adsorption (Speight, 1993; Mokhatab et al., 2006).

In the gasification process, one or more reactants, such as oxygen, steam, or hydrogen, are introduced into the system. These chemical reactants combine with solid carbon at the higher gasification temperatures, so increasing the gas yield while consuming char. The amount of char byproduct remaining on gasification is, in fact, essentially zero with biomass materials, while the small quantity of tars and oils evolved may be recycled to extinction. The introduced reactants also enter into gas phase reactions which, together with the shift in equilibrium and the change in relative reaction rates at the higher temperatures, results in a significantly better-quality gas than that obtained on pyrolysis. Important distinctions between pyrolysis and gasification are therefore the improved gas yield and the elimination of solid and liquid byproducts. One major advantage with gasification is the wide range of biomass resources available, ranging from agricultural crops and dedicated energy crops to residues and organic wastes. The feedstock might have a highly varied quality, but still the produced gas is quite standardized and produces a homogeneous product. This makes it possible to choose the feedstock that is the most available and economic at all times (Prins, 2005).

In terms of process management, there are various types of gasifiers which, although discussed elsewhere (Chapter 6) (Speight, 2008, 2011, 2013) deserve mention here.

The air-blown direct gasifiers operated at atmospheric pressure and used in power generation – fixed bed updraft and downdraft and fluidized bed bubbling and circulating – are not suitable for biomass-to-liquid production. In addition, downdraft fixed bed gasifiers face severe constraints in scaling and are fuel inflexible, only being able to process fuels with well-defined properties. Updraft fixed bed gasifiers have fewer restrictions in scaling but the produced gas contains a lot of tars and methane.

Fluidized bed gasifiers generally do not encounter limitations in scaling and are more flexible concerning the particle size of fuels. Nevertheless,

they still have limited fuel flexibility, due to a risk of slagging and fouling, agglomeration of bed material and corrosion. Therefore, the operating temperatures of air-blown fluidized bed gasifiers are kept relatively low (800 to 1000°C, 1470 to 1830°F). This implies the incomplete decomposition of feedstocks, unless long residence times are used. Fluidized bed gasifiers (especially the bubbling bed ones) tend to contaminate the product gas with dust. The oxygen-blown atmospheric or pressurized circulating fluidized bed gasifiers and the steam-blown gas or char indirect gasifiers are better solutions for biomass-to-liquids production. Both gasifying concepts reduce significantly the amount of nitrogen in the product gas. In the first case, it is achieved via substituting air with oxygen. In the second case, nitrogen ends up in the flue gas, but not in the product gas, because gasification and combustion are separated – the energy for the gasification is obtained by burning the chars from the first gasifier in a second reactor.

The gasification of biomass (such as e.g. wood scrap) is a well-known process, taking place in pyrolysis (oxygen supply far below what is required for complete combustion, the fraction called *equivalence ratio*) or fluidized-bed type of reactors. Conditions such as operating temperature determine whether hydrogen is consumed or produced in the process. Hydrogen evolution is largest for near-zero equivalence ratios, but the energy conversion efficiency is highest at an equivalence ratio of around 0.25. The hydrogen fraction (in this case typically some 30%) must be separated for most fuel-cell applications, as well as for long-distance pipeline-transmission. In the pyrolysis-type application, gas production is low and most energy is in the oily substances that must be subsequently reformed in order to produce significant amounts of hydrogen. Typical operating temperatures are approximately 850°C (1560°F). An overall energy conversion efficiency of around 50% is attainable, with considerable variations. Alternative concepts use membranes to separate the gases produced and many reactor types use catalysts to help the processes to proceed in the desired direction, notably at a lower temperature (down to approximately 500°C, 930°F).

Each type of biomass has its own specific properties which determine performance as a feedstock in gasification plants. The most important properties relating to gasification are (1) moisture content, (2) mineral content leading to ash production, (3) elemental composition, (4) bulk density and morphology and (5) volatile matter content.

The moisture content of biomass is defined as the quantity of water in the material and is expressed as a percentage of the material's weight. For gasification processes like gasification, preference is given to the relatively dry biomass feedstocks because a higher quality gas is produced, i.e. higher heating

value, higher efficiency and lower tar levels. Natural drying (in the field) is cheap but requires long drying times. Artificial drying is more expensive but also more effective. In practice, artificial drying is often integrated with the gasification plant to ensure a feedstock of constant moisture content. Waste heat from the engine or exhaust can be used to dry the feedstock.

Ash contents (which represents an inorganic content) of biomass are the inorganic oxides that remain after complete combustion of the feedstock. The amounts of ash between different types of feedstocks differ widely (0.1% for wood up to 15% for some agricultural products) and influence the design of the reactor, particularly the ash removal system. The chemical composition of the ash is also important because it affects the melting behavior of the ash. Ash melting can cause slagging and channel formation in the reactor. Slags can ultimately block the entire reactor.

The *elemental composition* of the biomass feedstock is important with regard to the heating value of the gas and to the emission levels. The production of nitrogen and sulfur compounds is generally small in biomass gasification because of the low nitrogen and sulfur content in biomass.

The *bulk density* refers to the weight of the material per unit of volume and differs widely between different types of biomass. Together with the heating value, it determines the energy density of the gasifier feedstock, i.e. the potential energy available per unit volume of the feedstock. Biomass of low bulk density is expensive to handle, transport and store. Apart from handling and storing behavior, the bulk density is important for the performance of the biomass as a fuel inside the reactor. A high void space tends to result in channeling, bridging, incomplete conversion and a decrease in the capacity of the gasifier. The bulk density varies widely (100 to 1000 kg/m3) between different biomass feedstocks not only because of the character of the biomass but also as a result of the way the biomass comes available (chips, loose, baled).

The amount of volatile products (*volatile matter content*) has a major impact on the tar production levels in gasifiers. Depending on the gasifier design, the volatile matter leaves the reactor at low temperatures (updraft gasifiers) or it passes through a hot incandescent oxidation zone (downdraft gasifiers) where they are thermally cracked. For biomass materials the volatile matter content varies between 50 and 80%.

Feedstock preparation is required for almost all types of biomass materials because of the large variety of physical, chemical and morphological characteristics. The degree to which any specific pretreatment is desirable will depend upon the gasifier. For example, the capacities and types of reactors (downdraft gasifiers are more strict to uniform fuel specifications than updraft gasifiers) are important aspects of biomass gasification.

Sizing of the feedstock may be necessary as different sizes are specified for different types of gasifiers. For small-scale fixed bed gasifiers, the cutting and/or sawing of wood blocks is the preferred form of fuel preparation. Chipped wood is preferred for larger-scale applications. The size range of chips can be chosen by screening such that the fuel is acceptable for a specific gasifier type. For medium-scale and large-scale fixed bed gasifiers wood chips from forestry or wood processing industries are produced by crushers, hammer mills, shredders and/or mobile chippers (particularly for thinnings from landscape conservation activities). Most of these sizing apparatuses are provided with a screen. Dependent on the feedstock morphology and characteristics (hardness) the throughput or capacity varies considerably.

Drying of the biomass fuel is advisable if fresh wet materials (moisture content 50 to 60% on wet basis) are to be gasified. Lowering the moisture content of the feedstock is associated with a better performance of the gasifier. Utilizing the exhaust gases from an internal combustion engine is a very efficient way to do so. The sensible heat in engine exhaust is sufficient to dry biomass from 70% down to 10%. Rotary kilns are the most applied dryers. The energy costs of drying are high, but these can be outweighed by the lower downstream gas cleaning requirements for dried feed.

Densification, such as *briquetting* or *pelletization*, are important techniques to densify biomass materials for increasing the particle size and bulk density. The reasons for biomass include (1) densified biomass is less expensive to transport, (2) densified products are easier to store and handle and (3) densification enables certain biomass feedstocks to be gasified in a specific gasifier.

The calorific value of the gas is the prime factor for power generation – the higher the value, the better. Hence, the availability in the gas of any compounds that increase calorific value is generally welcomed. Product gas contains carbon monoxide (CO), hydrogen (H_2) and various hydrocarbons [methane (CH_4), ethylene (C_2H_4), ethane (C_2H_6) tars and chars]. The presence of inert components [water (H_2O), carbon dioxide (CO_2) and nitrogen (N_2)] is also acceptable, provided they are kept within certain limits.

Environmental concerns include the disposal of associated tars and ashes, particularly for the fluidized bed reactors, where these substances must be separated from the flue gas stream (in contrast to the pyrolysis plants, where most tar and ash deposits at the bottom of the reactor). Concerns over biomass transportation are similar to those mentioned above for fermentation and a positive fertilizer effect can also in many cases be derived from the gasification residues.

Biomass ash has also the potential to be used as a clarifying agent in water treatment, as a wastewater adsorbent, as a liquid waste adsorbent, as a hazardous waste solidification agent, as a lightweight fill for roadways, parking areas and structures, as asphalt mineral filler, or as a mine spoil amendment.

Direct conversion processes, i.e. the combustion of biomasses, encounter the same problems as those in the case of coal or other solid fuels. The conversion of biomass into other useful forms such as synthetic gases or liquid fuels is considered an alternative way to make use of biomass energy. Gasification is an effective and well-known technology which has been applied to coal but the technology developed for coal is not exactly suit to biomass utilization because of the different physical and chemical properties between coal and biomass.

The Fischer-Tropsch process is used to produce liquid synthetic fuels (synfuels) from gasified biomass. In the process, carbonaceous material is gasified and the gas is processed to make purified synthesis gas, which is then converted into gasoline and diesel-range hydrocarbons (Khodakov et al., 2007; Chadeesingh, 2011). Other processes are also available for converting biomass to liquids: (1) flash pyrolysis, which produces bio-oil, char and gas at temperatures on the order of 350 to 550°C (660 to 1020°F) and residence times <1 second and (2) catalytic depolymerization in which heat and catalysts to produce diesel fuel from hydrocarbon wastes.

The products from the Fischer-Tropsch reactor are naphtha, diesel and chemical feedstocks (biogas can also be used in place of solid biomass). Synthetic diesel is sulfur and fragrance free, has a cetane number above 70 and could be used straight or blended with ordinary diesel/biodiesel to improve properties (in the EU, diesel accounts for a growing share of vehicle fleet). Automakers may see this as an opportunity to develop high efficiency ultra-low emissions engines in the future.

References

Ahmed, I. 2001. "Oxygenated Diesel: Emissions and Performance Characteristics of Ethanol-Diesel Blends in CI Engines." SAE Paper No. 2001–01-2475. Society of Automotive Engineers, Warrendale, Pennsylvania.

Albertazzi, S., Basile, F. and Trifirò, F. 2007. *Gasification of Biomass to Produce Hydrogen.* In Renewable Resources and Renewable energy: A Global Challenge. M. Graziana and P. Fornaserio (Editors). CRC Press-Taylor & Francis Group, Boca Raton, Florida. Chapter 6.

ASTM D975. *Standard Specification for Diesel Fuel Oils.* Annual Book of Standards, ASTM International, West Conshohocken, Pennsylvania.

ASTM D6751. *Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels.* Annual Book of Standards, ASTM International, West Conshohocken, Pennsylvania.

ASTM D7467. *Standard Specification for Diesel Fuel Oil, Biodiesel Blend (B6 to B20).* Annual Book of Standards, ASTM International, West Conshohocken, Pennsylvania.

Beeharry, R.P. 2001. *Carbon Balance of Sugarcane Bioenergy Systems.* Biomass Bioenergy 20, 361–370.

Butkus, A. and Pukalskas, S. 2004. *Research into the Influence of Ecological Petrol Additives in the Automobile Laboratory*. Transport, 19(1): 24–27.

Chadeesingh, R. 2011. *The Fischer-Tropsch Process.* The Biofuels Handbook. J.G. Speight (Editor). Royal Society of Chemistry, London, United Kingdom. Part 3, Chapter 5.

Dale, B.E. 2007. *Thinking Clearly about Biofuels: Ending the Irrelevant Net Energy' Debate and Developing Better Performance Metrics for Alternative Fuels.* Biofuels Bioprod. Biorefin., 1: 14–17.

Davis, S.C. Anderson-Teixeira, K.J. and DeLucia, E.H. 2009. *Life Cycle Analysis and Ecology of Biofuels.* Trends in Plant Science, 14(3): 140–146.

Elsayed, M.A., Matthews, R. and Mortimer, R.D. 2003. Carbon and Energy balances for a Range of biofuels Options. Project No. B/B6/00784/REP URN 03/836, Resourfes Research unit, Sheffield Hallam University, Sheffield, South Yorkshire, United Kingdom.

Fargione, J., Hill, J., Tilman, D., Polasky, S. and Hawthorne, P. 2008. *Land Clearing and The Biofuel Carbon Debt.* Science, 319: 1235–1238.

Field, C.B., Campbell, J.E. and Lobell, D.B. 2007. *Biomass Energy: The Scale of the Potential Resource.* Trends Ecol. Evol., 23: 65–72.

Gnansounou, E., Dauriat, A., Villegas, J. and Panichelli, L. 2009. *Life Cycle Assessment of Biofuels: Energy and Greenhouse Gas Balances.* Bioresource Technology, 100: 4919–4930.

Hill, J., Nelson, E., Tilman, D. Polasky, S. and Tiffany, D. 2006. "Environmental, Economic and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels." Proceedings, National Academy of Sciences, 103(30): 11206–11210.

Hira, A. and Singh, S. 2012. *Performance and Emission Characteristics of a CI Engine Using Blends of Ethanol and Biodiesel with Diesel*. International Journal of Engineering Research & Technology (IJERT), 1(5): 1–12.

Junginger, M., van Dam, J., Zarrilli, S., Ali Mohamed, F., Marchal, D. and Faaij, A. *2010 Opportunities and Barriers for International Bioenergy Trade*. Task No. 40, IEA Bioenergy, International Energy Agency, Paris, France. Also published in: Energy Policy, 2011, 39(4): 2028–2042.

Kaltner, F., Azevedo, G.F.P., Campos, I.A. and Mundim, A.O.F. 2005. "Biofuels for Transportation: Brazilian Potential and Implication for Sustainable Agriculture and Energy in the 21st Century." Prepared for the Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Rio de Janeiro, Brazil. November. Page 23.

Khodakov, Chu, W. and Fongarland, P. 2007. *Advances in the development of novel cobalt Fischer-Tropsch catalysts for synthesis of long-chain hydrocarbons and clean fuels.* Chem. Rev., 107(5) 1692–1744.

Kumar, A. and Sokhansanj, S. 2007. Switchgrass (Panicum vigratum, L.) *Delivery to a Biorefinery Using Integrated Biomass Supply Analysis and Logistics (IBSAL) Model.* Bioresour. Technol., 98, 1033–1044.

Kumar, S., Chaube, A., Jain S.K. 2012. *Critical Review of Jatropha Biodiesel Promotion Policies*. India Energy Policy, 41: 775–781.

Lee, S. 2007. *Clean Liquid Fulles from Coal. In: Handbook of Alternative Fuel Technologies.* S. Lee, J.G. Speight and S. Loyalka. CRC Press, Taylor & Francis Group, Boca Raton, Florida. Chapyter 3. Page 81–124.

Leenus, J.M., Geo, V.E. and Prithviraj, D. 2011. *Effect of Diesel Addition on the Performance of Cottonseed Oil Fuelled DI Diesel Engine.* International Journal of Energy and Environment, 2(2): 321–330.

Lettens, S., Lettens S., Muys B., Ceulemans R., Moons E., Garcia J. and Coppin P. 2003. *Energy Budget and Greenhouse Gas Balance Evaluation of Sustainable Coppice Systems for Electricity Production.* Biomass Bioenergy, 24: 179–197.

Malca, J. and Freire, F. 2006. *Renewability And Life-Cycle Energy Efficiency of Bioethanol and Bio-Ethyl Tertiary Butyl Ether (bio-ETBE): Assessing the Implications of Allocation*. Energy, 31, 3362–3380.

Mokhatab, S., Poe, W.A. and Speight, J.G. 2006. *Handbook of Natural Gas Transmission and Processing*. Elsevier, Amsterdam, Netherlands, 2006.

Müller, M. and Hübsch, Ute. 2005. *Dimethyl Ether. In: Ullmann's Encyclopedia of Industrial Chemistry,* Wiley-VCH, Weinheim, Germany.

Pandey, S., Sharma, A. and Sahoo, P.K. 2012. *Experimental Investigation on the Performance and Emission Characteristics of a Diesel Engine Fuelled with Ethanol, Diesel and Jatropha Based Biodiesel Blends.* International Journal of Advances in Engineering & Technology, 4(2): 341–353.

Prins, M.J. 2005. "Thermodynamic Analysis of Biomass Gasification and Torrefaction." Ph.D thesis, Technische Universiteit Eindhoven. ISBN: 90–386-2886–2. http://alexandria.tue.nl/extra2/200510705.pdf, accessed August 6, 2013.

Shapouri, H., Duffield, J.A. and Wang, M. 2003. *The Energy Balance of Corn Ethanol Revisited.* Am. Soc. AgricultEng., 46: 959–968.

Speight, J.G. 1993. *Gas Processing: Environmental Aspects and Methods.* Butterworth-Heinemann, Oxford, United Kingdom. 1993.

Speight, J.G. 2008. *Synthetic Fuels Handbook: Properties Process and Performance.* McGraw-Hill, New York.

Speight, J.G. (Editor). 2011. *The Biofuels Handbook. The Royal Society of Chemistry*, London, United Kingdom.

Speight, J.G. 2013. *The Chemistry and Technology of Coal 3rd Edition*. CRC Press, Taylor & Francs group, Boca Raton, Florida.

Speight, J.G. 2014. *The Chemistry and Technology of Petroleum 5th Edition.* CRC Press, Taylor & Francs group, Boca Raton, Florida.

Tilman, D.. Hill, J. and Lerhman, C. 2006. *Carbon-Negative Biofuels from Low-Input High-diversity Grassland Biomass*. Science, 314: 1598–1600.

US DOE. 1992. Energy Policy Act of 1992. Congress of the United States of America, Washington, DC. https://www1.eere.energy.gov/femp/regulations/epact1992.html#def, accessed August 5, 2013.

US DOE. 2008. "Clean Cities Fact Sheet." Report No. DOE/GO-102008–2542. Energy Efficiency and Renewable Energy Vehicle Technologies Program, United States Department of Energy, Washington, DC. http://www.biodiesel.org/docs/ffs-basics/clean-cities-fact-sheet-biodiesel-blends-april-2008.pdf?sfvrsn=4, accessed August 5, 2013.

Von Blottnitz, H. and Curran, M. 2007. *A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas and environmental life cycle perspective*. J. Clean. Prod., 15: 607–619.

Worldwatch Institute. 2006. "Biofuels for Transport: Global Potential and Implications for Energy and Agriculture." Prepared by Worldwatch Institute for the German Ministry of Food, Agriculture and Consumer Protection (BMELV) in coordination with the German Agency for Technical Cooperation (GTZ) and the German Agency of Renewable Resources (FNR). Earthscan, London, United Kingdom.

5

Social Aspects

5.1 Introduction

Biofuels begin as *biomass* such as crops, wood or other living matter (Chapter 1). Biomass is a renewable resource that has the potential to supply a limited portion of international energy needs. The road transport sector is already using biofuels and there will soon be biofuel substitutes for railway and aircraft fuels. The interest in biofuels, bioenergy production and investment has been driven largely by the policies of national governments, both in developed and developing countries. However, there are legitimate sustainability-related concerns cited by a large number of stakeholders concerning biofuels and bioenergy, ranging from environmental issues, loss of biodiversity, carbon emissions, land use issues and detrimental social impact (Fritsche et al., 2005; Rajagopal and Zilberman, 2007; Ritz and Janssen, 2008; Blanco Fonseca et al., 2010; Dale et al., 2010; Elbehri et al., 2013). So varied are the potential feedstock, agronomies, conversion processes and end uses that the outcomes are dependent on how they are combined and regulated. Given

the complexity of the issues surrounding biofuels and growing of feedstock regarding policy, regulations, interactions etc. could lead to uncertainty in achieving a wide social mandate (Fritsche et al;., 2005). Possible approaches to address such uncertainty could be through voluntary governance tools, non-state certification schemes or enforced biofuel certification (Echols, 2009).

Current and future support of biofuels could have important implications for global land use, environmental issues, as well as the relevant social issues, which must be managed (Fritsche et al., 2005). In particular, it is likely to accelerate the expansion of land under crops particularly in Latin America and Asia. Although this may provide new income opportunities for poor rural populations, it carries the risk of significant and hardly reversible environmental damages. Recently, more attention has been paid to the effects of land use changes by distinguishing between direct land use changes (where land already used for agriculture is switched to produce biofuel feedstock) and indirect land use changes (where land that may or may not be currently used for agriculture is converted to produce non-biofuel crops in response to biofuel-driven displacement of commodity production in a different region, country or even continent) (Kim et al., 2009).

While direct land use changes are considered in various studies, indirect land use changes are more often ignored. However, under the right conditions and with effective systems in place and the appropriate management of any social issues, biofuels can be produced sustainably. Still, environmental risks and benefits have attracted significant attention and dominated sustainability discussions on biofuels to date. Increasingly, project developers are conducting environmental impact assessments as part of an attempt to demonstrate the sustainability of biofuels to potential purchasers, importing nations and certification schemes (Echols, 2009).

The social aspects that remain are not being treated with equal weight. This is due in part to the lack of baseline social impact data as well as the complexities of social impacts which cannot always be dealt with at a local level and require action from multiple stakeholders. In many countries, the demand for biofuels and associated targets is greater than the potential domestic supply. Thus it will be necessary to source biofuel feedstocks from countries where there is sufficient arable land and favorable agricultural conditions. These are likely to be developing countries, which is where the social impacts will come into play (Fritsche et al., 2005).

One of the most significant social impacts related to biofuel stems from land use change. Where arable land is converted from the production of food to biofuel cultivation, significant direct and indirect impacts may occur. Critics argue that indirect land use change is unavoidable and that

sustainability certification schemes will deliver only limited environmental protection or benefits and the livelihoods of the poor working class may only be marginally improved. The impact on food security is one of the primary concerns, in terms of scarcity of food supply, food production levels and impacts to price. At a national level, the displacement of food production means that the country may become reliant upon food imports to make up the deficit in domestic food production. Thus, the country becomes vulnerable to the commodity market, food price fluctuations and potential food supply shortages; in other words, dependence on, say oil imports, is transferred to a dependence on food imports and if food prices rise or biofuel prices fall, the country becomes vulnerable to food shortages.

In fact, the spreading concerns about the impact of increasing production of biofuels, possible competition for agricultural land and impact on the food prices require a realistic assessment and careful management since there are a number of various factors at play, including poor management of the agricultural sector during the last decades, unfavorable weather conditions, lack of investment in production capacity and infrastructure, distorted agricultural markets and the dismantling of support policies for domestic market in developed countries which all might have contributed to the recent increases in food prices all over the world (Blanco Fonseca et al., 2010; WEC, 2010).

One solution that biofuel advocates have put forward is to use so-called *abandoned* or *marginal land* for the production of biofuel. However, this is still likely to entail a range of social impacts as today there is almost no such thing as empty land which is still able to support crop cultivation. In reality, governments and regulators who may be in favor of biofuels development for economic reasons apply the labels of abandoned or marginal lands. In developing countries, this type of land is often occupied by poor, minority or indigenous groups who depend upon the land for their livelihood. Such groups of people tend to lack political power or representation and often have no formal title to the land, which makes them vulnerable and thus are more easily displaced. There may also be the highly visible social issue of gender discrimination, whereby only the male representatives are consulted or are the ones to voice their opinions. The voices of women, who may have a greater understanding of the *real* social impacts due to their role in agricultural cultivation or domestic food and water harvesting, are not typically heard or their words fall upon deaf ears.

Typically, it is argued by producer governments that biofuel production will lead to an increase in jobs and alternative livelihoods for the rural poor who are often dependent on subsistence farming, as well as positively

stimulate economic development. This might hold true in some cases. However, it remains to be seen how likely these benefits are to arise and whether the social costs involved resulting from biofuel production would outweigh these beneficial claims made by proponents. Indeed, by simply advocating the positives about biofuel production in terms of generating employment and income, it does not automatically translate into the notion that only positive social impacts will result. The opportunities must be assessed against alternative livelihood options that would realistically be available to the local people and the populations most directly affected. For instance, the agricultural sector is well-known for the high risk of poor working conditions.

In the context of the timing of this book, the policies and sustainability criteria of many developing countries do not sufficiently take into account the complexities of land use change and the social impacts outlined above, to enable carefully designed mitigation strategies that would result in a win-win approach for those in biofuel producing countries as well as consumer countries. These concerns discussed above have driven the development of regulations and international certification schemes. There should also be a movement to ensure that biofuel production in developing countries contributes to sustainable development. This will require that not only environmental and economic issues are taken into account, but also social issues need to be included to a greater extent in the future.

Another way to ensure the sustainability of biofuels and assurance of minimal social impact is by application of voluntary certification mechanisms. Existing certification schemes tend to only include limited environmental and social aspects but should also apply to social issues such as (1) human rights, (2) working conditions, (3) health and safety, (4) child labor, (5) freedom of association and collective bargaining rights, plus (6) social benefits to local community and rural development.

Social impact indicators play a key role in enhancing the credibility and acceptance of sustainability certification. However, the development of appropriate indicators that take into account locally significant issues and the ability to verify these indicators in order to ensure a positive social outcome is challenging. This is due in part to the difficulty of monitoring social criteria and enforcing adherence to social policies in developing countries, which is in turn dependent upon national regulatory and enforcement systems that are often under staffed and ineffective. Furthermore, there is an increasing demand for standards to be able to take into account nuanced social impacts that are locally diverse. In order to be effective, this would require international governance and support.

Increasingly, environmental impact assessments are being conducted at a local level by biofuel project developers. Currently, social impact assessments are not mandatory in all countries and there are no standards for social life-cycle assessment for biofuels (Blom and Solmar, 2009). Regions where biofuels are currently being developed or likely to be developed in future are often areas where the social issues will be the most complex. These are also often the areas where project developers have little available data to use as baselines. However, developers ignore social impacts at their peril as they pose serious risk to biofuels cultivation and development in many of the geographies where biofuels will be produced.

Care needs to be taken to ensure that the challenges in determining the impact of biofuel cultivation upon local communities do not hinder sound projects from going ahead. It is for this reason that social impact assessment and certification requirements must be progressive. It is important that all social issues are acknowledged and that biofuel cultivation fosters positive social impacts over time, with a view to continuous improvement, rather than ignoring the social issues or failing to acknowledge that existing (in 2013) regulatory or certification schemes are sufficient (Echols, 2009).

This chapter discusses the social aspects of the management of biofuels. The development of agriculture and rural areas are often touted benefits of biofuel production as they can be vehicles for expanding markets and creating employment. The role of producing value-added products and subsidies in the development of a biofuel economy is also explored (Harmer, 2009). Uses and potential strains on the population such as supplementing typically imported fuels and the fuel vs. food debate must also be considered. Finally, we discuss logistical concerns as infrastructure, transport and delivery and policies and regulations.

5.2 Agricultural and Rural Development

Henry Ford and Rudolph Diesel used plant oils as liquid fuels for IC engines; this may have been a way of expanding the market for early biofuel programs aimed at supporting agricultural economies. If so, little has changed as most biofuel production efforts are still set up primarily to help domestic agricultural producers and rural economies. Most of the world's poor reside in farming regions and depend on rural agriculture for a living. However, their livelihoods are increasingly threatened by the expansion of mechanized industrial agriculture and this has contributed to an exodus of migrant workers to the cities where economic prospects are not much better. Even in the developed world, farming populations

are on the decline as larger and more capital intensive farming operations displace jobs in the sector. *First-generation* biofuels that use sugar and starch crops (ethanol) and oilseed crops (biodiesel) as feedstock compete directly with demand for these crops as food or feed. *Second-generation* biofuels are typically produced from biomass from nonfood sources, including lignocellulosic biomass, waste matter from food crops or residues from other non-food processes. It follows that their land-use implications depend strongly on the specific feedstock and the management of land use.

Production of first-generation biofuels results in *by-products* of commercial value. In particular, the production of ethanol from grains, using a dry milling process, yields dried distillers grains (DDG), which is used in pig, poultry and ruminant feeds. Wet-milling processes for grain-based ethanol produce various by-products, including gluten feed and gluten meal, which are both used as animal feed and also demanded by the food industry. The residual cane waste (bagasse) from ethanol production from sugarcane is used in electricity production. By-products of biodiesel production are oil meals and oilcakes (animal feed) and glycerin. The latter has largely replaced synthetic glycerol in the pharmaceutical and the cosmetics industries and is finding a range of other uses. It is used as a dietary supplement for poultry and research is underway on its use in ruminant diets.

When assessing the impact and future prospects of biofuel production, these commercially valuable by-products must be taken into account, for two reasons. First, if by-products are used for animal feed, the animal feed displaced by using a feed-grain crop as feedstock does not have to be completely replaced by new crops. This has implications for the management of land use and food production capacity. Second, the price received for the by-product is part of the supplier's sales revenue, which alters the parameters of the competition between the biofuel and the corresponding fossil fuel. Furthermore, the by-products may themselves be used for energy generation (for example, bagasse, a by-product of ethanol derived from sugarcane, is used to produce steam for electricity generation in Brazil, Mauritius and Hawaii).

Second-generation biofuels promise to deliver higher biofuel yield performance. Dedicated cellulosic energy crops (such as reed canary grass) can produce more biofuel per hectare (2.47 acres) because the entire crop is used as fuel feedstock. These crops, like food crops, are land-using, although some may be grown on poor land that would normally not be used for food production but which still requires competent management. By contrast, in the case of waste products (agricultural and non-agricultural)

that would otherwise be disposed of, the *additional* land used to produce the feedstock is negligible, resulting in theoretical very high biofuel yields per hectare and zero competition with food production.

Small farmers are typically less able to compete with large producers and in the absence of land tenure and supporting agricultural policies may lead to marginalization of small land holders. The social and techno-economic analysis of biodiesel production in Peru indicate the challenges faced by small land holders such as cost implications, lack of access to inputs, low technology, poor training, low yields (10 to 15 ton/ha/yr. for oil palm as opposed to 25 ton/ha/yr. for industrialized production; ha = hectare or 2.47 acres), limited access to technical and financial services, suffering from economies of scale and the potential to be sidelined by industrial scale producers (Quintero et al., 2012).

On the social front, biofuels may be promoted as community fuel, cultivated and produced in a co-operative model with budgetary support from government and private sector sponsored social schemes. Researchers stress the importance of alliances between government, private enterprise, small-holders and commercial entities (job creation, rural and sustainable economic development) in realizing national biofuel objectives. Biofuels hold the promise to aid rural development, reverse some of the risks posed by mechanized production and increase market demand for agricultural products (boost agricultural employment and substitute for agricultural subsidies). On the downside, notably the price of food going up and land-grabbing by plantation developers is well documented in the literature (World Watch Institute 2006). In Mozambique, production schemes that favour small farmers provided employment for unskilled labour, increased food crop yields (access to improved technology) and improved the economic outlook for rural labourers (poverty alleviation).

Policy measures for promoting the production and use of biofuels can be characterized according to various dimensions: the point at which they are applied in the production and marketing chain, whether they work by altering relative prices or by direct regulation and whether the cost of the support falls ultimately on the taxpayer or the fuel consumer (OECD 2008; Pelkmans et al., 2008). In any case, conscientious management of the land and the products must be in place to ensure support for the land owner.

5.3 Expanding Markets

In many cases, the term *biofuel* is commonly used with reference to liquid transportation fuels – specifically ethanol and biodiesel – derived from

agricultural, forest or any other organic material (feedstock). Current global concerns about fossil fuel prices and availability, a renewed quest by many countries for energy independence and widespread awareness of the need to reduce greenhouse gas emissions have been the main reasons for many countries – developed countries *and* developing countries – to seek alternative energy sources. Biofuels have captured considerable attention because of the relative abundance of feedstocks in all regions, their easy utilization in combustion engines for transportation, compatibility with existing fuel distribution infrastructure and because they can provide a new end market for agricultural commodities, therefore revitalizing rural areas. The United States invested in biofuels as a way to address the fuel shortages induced by the embargo and to reduce dependence on imported oil. Brazil's objective was to reduce the pressure on its balance of payments due to the rising cost of fossil fuel imports. Although Brazil and the United States launched their ethanol program more than 30 years ago, only Brazil made it a priority to build upon the initial efforts and make ethanol a significant component of the domestic fuel supply (UNCTD, 2009).

Unlike fossil fuels, biomass for energy has hardly been traded regionally or nationally and even less so internationally, most trading has occurred at the local level but this is set to change as seen in densified biomass (pellets and chips) and liquid biofuels (ethanol and biodiesel) becoming major traded commodities (Chapter 3, Biofuel Policies, Section 3.5, International Trade) (Trindade, 2005a, 2005b). In fact, trade in biomass and biofuels will also be subject to greenhouse gas emission policies, if not from the importing county but also from the exporting country (Al-Riffai et al., 2010; Meyer et al., 2013). Large scale, export-oriented production systems in developing countries could yield positive social impacts; but this hinges on government led social innovations targeting poor small land holders (interventions on the ground) and the certification of the supply chain (Chapter 3, Section 3.4 Standards and Certification Schemes). The demand for biofuels might be significant but recent campaigns by non-governmental organizations (NGOs) have severely undermined biofuels' ethical credentials (NCB, 2011).

Furthermore, it is increasingly understood that 1st-generation biofuels (produced primarily from food crops such as grains, sugar beet and oil seeds) are limited in their ability to achieve targets for oil-product substitution, climate change mitigation and economic growth. Their sustainable production is under review, as is the possibility of creating undue competition for land and water used for food and fibre production (IPIECA, 2012). A possible exception that appears to meet many of the acceptable criteria is ethanol produced from sugarcane (Sims et al., 2008).

The cumulative impacts of these concerns have increased the interest in developing biofuels produced from non-food biomass. Feedstocks from ligno-cellulosic materials include cereal straw, bagasse, forest residues and purpose-grown energy crops such as vegetative grasses and short rotation forests. These "2nd-generation biofuels" could avoid many of the concerns facing 1st generation biofuels and potentially offer greater cost reduction potential in the longer term.

A persistent and collaborative restorative effort for the case of 'green' fuel will require better legislation and radically improved monitoring and enforcement practices in countries where the very absence of these has led to and is still causing, large scale destruction of habitats that are carbon sinks of global importance (oil palm has been associated with complaints of loss of land by indigenous people and a failure to achieve sustainable livelihood improvements for small farmers and can lead to future poverty for many). In response to these problems, prominent international campaigns have increased the pressure on palm oil investors, buyers and producers across complex production networks.

It is argued that in developed countries the social benefits for producing transport biofuels are highly debatable (they do not address the social problems of excessive car usage and farming communities, though small, are not particularly poor and have been heavily subsidized for decades). It will be expected that wealthy countries pay a premium price for socially and environmentally certified biofuels from developing biofuel producer countries as part of their social responsibility (will raise moral, technical and administrative issues as these certified premium products would have to be specially marketed and branded). Growth in the biofuels market offers particular benefits to agricultural regions and is a way of increasing the value of the world's farm products. However higher crop prices do not necessarily translate into better conditions for rural communities, and may raise the price of inputs to the rural poor while benefits fail to trickle down to the poorest. Historically, biofuel programs have served the purpose of providing farmers with expanded markets and price support and even today biofuel programs still help to maintain or increase the price of certain agricultural feedstock.

In the US, rising ethanol production has absorbed a steadily larger share of the country's corn crop, from 12% in 2004 to 18% 2005-2006 and to 20% (2012) (US DOE and EERE, 2006, RFA, 2005) rising demand for corn to ethanol is expected to keep prices high. In the EU, the biodiesel market has been developed in large part due to support given to the growers of oil seeds and restrictions placed on acreage under oilseed for food caused farmers to cultivate rapeseed and sunflower for biodiesel production (approximately

20% of EU rapeseed is now sold for fuel) (Jones, 2005). From the literature a number of potential barriers to market expansion (exporting and importing countries and stakeholders) – economic, technical, logistical, international trade, ecological, social, methodological and legal – appear to raise more questions and add to the complexity rather than provide answers refer to Chapter 2 Environmental Aspects and Chapter 3 Biofuel Policies for an expanded treatment.

In Brazil, the *Proalcool* programme was designed to boost the local ethanol market and keep sugar prices high. This has led to an expansion of sugarcane cultivation (50% of the country's sugar is converted into ethanol, the biofuel programme has resulted in a doubling of planted acreage) (World Watch Institute 2006). Brazil's sugar mills are now integrated facilities and hedge between sugar or ethanol production (driven by market demand). High gasoline prices and increased demand for ethanol fuel in Brazil have been key factors in keeping global sugar prices high.

While higher crop prices are clearly beneficial to some producers, other industries can suffer, especially those that purchase agricultural commodities. In Europe, increased demand for biodiesel has caused a shortage of rapeseed oil and food manufacturers that use rapeseed oil in preparations must look for suitable alternatives. Australian livestock farmers are wary that a grain ethanol programme will cause a jump in feed prices and make their products more expensive (and may lead to greater losses than gains from displaced oil imports). Similarly, in the US, hog and poultry producers along with the operators of grain processing and exporting terminals share similar sentiments.

A number of alternative biomass feedstocks (sugar, starch, plant or animal oils) and conversion technologies (conventional and advanced) are available (Chapter 1). Biomass feedstock are diverse and markets for underutilized forms as MSW and agro-forestry residues need to be developed to take the competitive pressure off crops that are major inputs to other industries. For example, jatropha bushes for biodiesel could be grown on wasteland. This avoids competing with food crops for arable land, however to provide the necessary per hectare return to be profitable as a biofuel feedstock they require crop management, irrigation, fertilizers and better land use rather than competition for land resources that could be used for food production. Crop residues, forest undergrowth and thinnings, switchgrass, miscanthus and dedicated energy crops (perennials) are lignocellulosic biomass feedstocks that could be converted to fuels using advanced cellulosic conversion technologies. Brazilian sugar mills have amassed huge quantities of bagasse (stems after juice is extracted), leaves and tips (lignocellulosic sources). Similarl sources of accumulated residues

can come from large scale agro-processing, saw mills, pulp and paper *etc*. New markets for residues could open new opportunities for rural communities; however, diverting residues to biofuel production may deprive other industries (waste derived solid fuels, charcoal, fiber products, mulch, animal bedding etc.) from their major feedstock and raise prices.

5.4 Creating Employment

Employment in the biofuels industry is and will continue to be, a function of the particular feedstock used for production and requires careful management. Some feedstocks require much more intensive labour input than others in the seeding, cultivation and harvesting required to render feedstocks suitable for biofuel production. Employment in biofuels will also be affected by environmental concerns or limitations. For example, although the theoretical production of biofuels in a given region might be high, the environment may constrain production below the theoretical value owing to water shortages, unstable rainfall, soil erosion or nutrient depletion. Such constraints would inevitably reduce the employment potential.

The biorefinery process refers to the established (and emerging) chemical, biological and mechanical technologies used to convert the feedstock to fuel. Some biorefineries are now quite flexible in that they have the capacity to process a range of feedstocks and materials interchangeably, allowing them to react to price trends more easily. Some biorefineries are less labor-intensive than others because their processes are more automated, which may result in fewer jobs. Advanced biorefineries are envisioned to serve as the foundation of second-generation biofuels, but significant modification of first-generation refineries is also likely. Employment will also be affected by the specific application of the biofuel. For example, there could be employment implications if biofuels caused a malfunction in the vehicle types used in transportation. Beyond the employment opportunities arising from the production of biofuels are the technological advances from employment in research and development (APEC, 2010).

Thus, biofuel programs help generate demand for agricultural products and have the potential to significantly increase employment in rural areas (generate additional income within the agricultural sector and open export markets for developing countries). In the US, the ethanol industry is credited with having created 147,000 to 200,000 jobs (farming to plant construction), in Brazil 500,000 and in the EU 45,000 to 75,000 jobs (US DOE and EERE, 2006; RFA 2005; NREL 2000). In terms of employability parameters, India has high hopes for its biodiesel programme to generate increased employment,

alleviate poverty and to upgrade its rural non-farming sector, in addition to providing energy security. Rural labourers (unskilled employment) and small land holders will have an opportunity to be directly involved and generate income from the growing and harvesting of biofuel feedstock, depending on local needs. An example of this is seen in India where the public and private sectors are promoting the participation of small land holders in the cultivation of sweet sorghum for ethanol production. Private businesses provide farmers with seeds, supply contracts and access to local processing facilities and by so doing, they help to develop a village-based supply chain.

Emerging biofuel producer countries will be faced with the challenge of envisaging policy and implementing state sponsored social welfare schemes to provide livelihood with work (for example, nurturing Jatropha plantations on waste land in India and Sub Saharan Africa) and for meeting the livelihood needs of cultivators during the growing period of the plant. As biofuel programs become mainstream they will contribute to even greater employment in more countries. Such dramatic increases in job creation are achievable because biofuel production is labor intensive; the greater involvement of farmers in the production, processing and use of biofuels means they stand to benefit (ownership over more parts of the value chain, break the monopolistic hold of large processors who sometimes exert pressure on the producers).This will help to improve local economies as the farmers can benefit from production, marketing and distribution networks. Despite the benefits, barriers such as technical know-how, capital availability for start-up costs, lack of private sector capacity and support, market access and land tenure, continue to negatively impact small-scale bioenergy in developing countries.

Projects have been launched throughout Africa and Asia that seek to demonstrate successful, small-scale production models that can create income opportunities throughout the supply chain and increase added value for a wide range of farmers (Ewing and Msangi, 2009). Lessons can be learned from the Brazilian experience, where large sugarcane plantation owners took over small farms and resulted in violent social disruption, increased unemployment and landlessness (Bastos Lima. 2012). In developing countries many agricultural jobs are seasonal making it harder to maintain steady employment (sugarcane has such a history). To address this, plantation owners can provide off season work like planting and preparing the fields. This raises the wages of sugarcane workers, however, the disparity between wealthy land owners and laborers is a flash point and one of major discontentment.

Oilseed crops on the other hand may be more amendable to equitable and sustainable job creation largely because oilseed crops often must be

harvested manually. Little advantage is gained from using advanced harvesting machinery and the production of biodiesel is fairly straightforward (takes place at low temperatures and pressures and could be done on a small scale). Feedstock that is more labor intensive and straightforward to produce biodiesel holds promise for supporting poor farmers and providing liquid fuel to remote areas.

In India, the government provided incentives to impoverished families for the cultivation of jatropha and pongamia to support Indian biodiesel initiatives. Such non-edible energy crops do not directly compete with food uses and grow on degraded lands (type of land resources that the poor tend to rely on disproportionately for their livelihoods). Demonstration projects in Ghana, Mozambique, Zambia and Mali using jatropha for electricity and energy generation, soap making, lamp oil and as an organic seedcake fertilizer have met with some success.

Similarly, Brazil aims to generate employment for family farmers with the target of creating 400,000 jobs related to biodiesel production (Kaltner et al, 2005) where the focus will be on poverty alleviation and the government plans to institute regulations where biodiesel producers will be required to purchase a percentage of their oil seeds from family farmers.

Rural development initiatives will require extensive and continued government support to ensure success; some of these options may include the following:

i. Establishing cooperatives and small scale biofuel production facilities to allow small and medium sized producers to share in the economic gain and have a say in negotiations.
ii. Appropriate tax structures and fiscal policies with mandates to purchase from small producers. This will provide confidence to small farmers to try new crops and crop management systems in the firm belief they are ensured of fair prices and a decent livelihood.
iii. Provide financial, technical and material support for small-scale biofuel initiatives for rural energy needs, poverty alleviation, seeds, seedlings and know-how and market access.

Large farmers will be in a better position to increase production for biodiesel production than small farmers, as has been seen in Brazil where soybean oil is currently cheaper than castor and palm oil (which discourages the small farmers). In addition, a facility to produce biodiesel from cow tallow (which is 30% cheaper than soybeans) has been permitted to commence construction. When completed it is expected to produce

nearly 14% of the biodiesel required to meet the country's B2 (2% biodiesel blended with 98% diesel) blending mandate. This has led small farmers in the Northeast of Brazil to sell off their castor oil at 25-30% below the market price to middlemen as no government legal framework is in place to protect them from price gouging or to benefit them by sharing the profits available downstream in the biodiesel market.

5.5 Subsidies

Biofuel production and consumption has seen substantial increases over the last decade and this expansion has not been solely in response to market forces; rather, government policies, such as subsidies and the mandated use of biofuels, have been key factors. Government support for biofuels has been driven by the need to address concerns related to (1) energy security, (2) protection of the environment and (3) rural development. However, the cost-effectiveness of achieving these goals under current subsidy schemes is often low and subject to much debate and question.

Industrialized agriculture in the developed world has benefited tremendously from government subsidies resulting in gains in agricultural productivity to the point that farmers find it makes good economic sense to dump their overproduction on the world market at prices well below the cost of production. This creates a major problem for agricultural regions in the developing world which are more dependent on farm incomes, comprising in some cases at least 35% of GDP (agriculture accounts for < 2% of income and employment in developed countries) (Watkins and von Braun, 2003). Developed countries support their biofuel industries through a multiplicity of policies and instruments. Some examples of this include, giving grants to farmers, providing subsidies on goods and services, offering reduced-cost credit for capital expenditures (lower fixed cost, reduced investor risk and improved ROI) and fuel excise taxes and tax credits linked to volumes produced, sold or blended with petro-fuels.

Developing countries must lobby the industrialized ones for the removal of distorting agricultural subsidies; biofuels offer an opportunity for developed countries to boost the agricultural economies of developing countries. In the US and Europe, biofuel support programs have acted as a substitute for agricultural subsidies; the EU's growing demand for biodiesel has already resulted in the limiting of land for food production to minimize overproduction and subsequent dumping. In the US, an ethanol tax credit and various state blending mandates have served to displace a greater portion of the corn crop to ethanol production (reduction in corn

export growth, ethanol has surpassed exports as the bigger use of corn) (Wilcox, 2005). Despite the promise of biofuels to reverse the damage of agricultural subsidies imposed by industrialized countries, fundamental problems do exist. Farmers in developing countries will have a tough time penetrating markets in industrialized countries due to tariffs, duties and an assortment of trade barriers *e.g.*, agricultural lobbyists in developed countries will be adamant to protect their own domestic biofuel industries (Teixeira Coelho, 2005).

US and EU corn, soybean and rapeseed producers will be wary of ethanol and plant oils imported from Brazil and palm oil from Malaysia and Indonesia and if huge investments are made by the developed countries in advanced cellulosic conversion technologies to bring them to commercialization they will protect these as well. If joint international trade in biofuels is to be sustained, policy makers on both sides of the divide (major producing and consuming countries) must agree on a framework to enable developing producer countries to export their production to the developed countries who are trying to meet their bioenergy (and renewable energy) targets (Chapter 3 Biofuel Policies).

5.6 Biofuel Processing

The use of biofuels is growing around the world and a debate between biofuels supporters and opponents is intensifying. Given the rapidly increasing demand for energy, which is projected to double by mid-21st Century, it is expected that biofuels will become an important part of the global energy mix and make a significant contribution to meeting energy demand (WEC, 2010). Drivers for a wide introduction of biofuels vary across the world and include a broad range of issues from land-use to energy security, to economics and environment. The main management challenge for the future is to develop biofuels that do not compete with the food chain, which are sustainable and efficient both in terms of costs and energy and for which the carbon footprint is a net gain.

Thus, one of the main goals of developing the biofuels sector is sustainability. The sustainability driver is based on the three pillars of economic, social and environmental sustainability. In economic terms, biofuel production has to be cost-effective and competitive. In social terms, biofuel development can create a massive new demand in the agricultural economy. As biofuel production is an agricultural process, the same management elements and inputs contribute to its overall efficiency as for existing agricultural production systems.

Biofuel processing (conversion and production) can bring income and jobs to rural areas apart from the growing and harvesting of biomass feedstock (value added impact). This gives the farmers the opportunity to benefit from the profits in the late stages of the biofuel value chain. Biofuel processing jobs pay better than farming jobs, with refiners receiving higher wages than farm laborers. In Brazil, refiners (technical skills) work for wages approximately 30% higher than laborers in the cane fields and in the Center-South of the country sugar milling and ethanol fermentation account for over 40% of the jobs (Kojima and Johnson, 2005).

The sale of co-products is another means of boosting agricultural income and the economic viability of biofuel production plants. In the US, dried distiller's grain with solubles (DDGS) is a high protein residue from ethanol production that is used as livestock feed (cattle, pigs). Seed cake that remains after oil is extracted from jatropha seeds is a valued fertilizer and pesticide and the utilization of bagasse at integrated sugar and ethanol facilities for process heat and power production plays a key role in keeping the ethanol industry profitable.

Glycerine, a co-product of biodiesel production, is used in the making of soap, cosmetics, pharmaceuticals and lubricants. Similarly, ethanol can be converted to ethylene, an important petrochemical intermediary for the production of a wide range of chemicals, fabrics and plastics. Co-products must be carefully identified so as not to exceed the demand and create a market glut as has happened with glycerin in Europe (reducing price and undercutting the ability to benefit rural communities). In the US, 'wet mills' (corn-ethanol processing plants) are usually large, produce a range of co-products like corn oil, gluten feed, germ meal, starches, dextrin and sweeteners (comprises more than a ¼ of a wet mill's economic output) and are already rudimentary biorefineries since they produce fuel, electricity and specialty chemicals concurrently (Chapter 1 Fuels from Biomass, Section 1.7 – The Biorefinery Concept).

The construction of facilities (a corn ethanol mill, biodiesel transesterification plant) can bring a onetime boost to the local economy. The plant will also require maintenance, repair, upgrade and expansion from time to time. Transportation to and from the facility can generate revenue for truck and rail companies. The largest benefit will be the money spent by the community from their higher paying jobs; people buying their basic necessities close to where they live, paying taxes and contributing to the development of their community. Farmer owned facilities cause more money to be circulated in the local economy than traditional cooperatives and corporations and workers at local facilities also seem to support more jobs in their region.

5.7 Biofuels for Local Use

Small-scale biofuel production systems in rural areas when developed (bottom-up) by the people involved can be expected to share many of the characteristics of small-scale and localized systems in developed countries and potentially yield similar positive social impacts. In fact these systems could potentially yield additional social benefits if they were to extend (new) energy services to rural people who had not enjoyed these before. One of the most direct benefits that biofuels can provide rural communities is the fuel itself (used for cooking and lighting as opposed to transport), especially in places vulnerable to disruption in the supply of petroleum products, which is applicable to both developed and developing countries). In addition there is the potential time savings when women and children do not have to gather firewood as well as the health benefits of a cleaner form of energy. An investigation of the correlation between poverty, hunger and dependence upon biomass for household energy use provided insights as to the vulnerabilities that poor households face and how they resort to less nutritious diets and less-reliable or clean forms of energy (Ewing and Msangi, 2009).

In this respect, biofuels continue to become an increasingly important feature of the road transport fuel scene. Indeed, if biofuels are to become part of the mainstream fuel supply line they will need to conform to the requirements for transport fuels and be capable of being used by consumers without requiring any modifications to their vehicles. Fuels containing biofuels are common in many current markets (2013) and mixtures with gasoline and diesel fuel are currently retailed as main grade fuels in many markets. The more recent *flex fuel* technology vehicles may allow the mainstreaming of higher concentrations of biofuels within the fuel chain, as they are capable of utilizing biofuel-conventional fuel mixtures, in any proportion from 0 to 100% v/v (IPIECA, 2009).

These initiatives all aim to capitalize on the positive effects that biofuels can have on greenhouse gas (greenhouse gas) reduction, energy security and rural development. However, the large-scale introduction of certain biofuels can also have unwanted negative environmental and socioeconomic effects and these effects have recently spurred a worldwide public debate on the sustainability of biofuels, including their effect on food prices.

In most isolated regions, biofuels make good sense compared to petroleum products which are usually transported via pipeline, truck and rail (remote areas will have little distribution infrastructure, costs will be higher). Remote communities depend on liquid fuels for transport, heat, power, cooking and lighting, and liquid biofuels play an important role

as non-transportation fuels. In some poorer countries, rural women and children spend a great deal of time gathering fuel wood, locally produced biofuels could provide a source of clean burning, reliable and assessable fuel to such communities and provide welfare gains (in terms of time savings, health benefits, electrification, small machinery power etc.). Country planners will be faced with the complex task of balancing short term sectorial needs with strategic national priorities, for example incentives to grow feedstock for biofuel production for export. However, when factors such as employment, energy security, trade balance, food security, land use, domestic transport and export infrastructure and greenhouse gas reduction obligations are considered, exports may no longer be attractive.

It may make good economic sense for many countries with cash strapped economies to displace expensive petroleum imports with homegrown biofuels and forgo exports (sacrifice the benefit of being able to earn foreign exchange); economic planners will need to weigh these factors. Some countries (Tanzania, Mali and Senegal) use jatropha oil planted and processed in close proximity to villages to usurp the cost of purchasing diesel; the infrastructure for crushing, pressing and extracting the oil will need to be installed to facilitate villagers. Bagasse, a byproduct of sugarcane milling, is already used as solid fuel for process heating and electricity generation in Brazil, Mauritius and Hawaii, with the excess generation sold to the national grid. Grain stalks and wet biomass are anaerobically digested into biogas. Through such efforts, rural communities can begin harvesting a greater amount of local biomass energy now, without waiting for advanced cellulosic technologies.

5.8 Food Versus Fuel Debate

The debate over the impact of subsidized biofuel-production on food prices spiked in 2006–2008 when, in spite of worldwide record crop yields, global prices for traded food commodities, such as staple cereals and sugars, reached record highs (World Bank, 2011). Rising food prices sparked debate as to whether crop-based energy production could be sustainable for countries whose levels of food insecurity and poverty are still significant. These hikes in food prices corresponded with the introduction of biofuel consumption mandates in the United States, Europe and some other countries and rapid increases in global biofuel production (Jung et al., 2010). Experts argue that blending mandates are putting undue pressure on grain and oilseed markets, which are then driving up international food prices and affecting human welfare. Food prices decreased in 2009,

but then resumed their growth through 2010 to 2011. Crop-based biofuel production, increases in agricultural production costs, escalating energy prices and other pressures to the agricultural sector negatively impacted the cost of cereals for food and feed and caused widespread concern in countries who are large net importers of key grains and vulnerable to price shocks. Despite price increases, biofuel production can create employment, provide local energy options, benefit the poor and the food insecure by off-setting some of the risks associated with its production.

Literature supports four main dimensions of food security: (1) availability, (2) access, (3) stability and (4) utilization of food. Biofuel development impacts each of these and adversely affects food availability as land, labor, water and other resources are used for biofuel production instead of food. Emerging biofuel producer countries are challenged by weak or non-existent policy frameworks to guide their development programs and this negatively impacts food availability; in Tanzania over 700,000 ha of land has been set aside for biofuel production of which only 100,000 ha (14%) is estimated to be under current biofuel production. In Mozambique, only 10% of land was under cultivation in 2008 while the amount of land available for food and biofuel production was 30 million ha (Renewable Fuels Agency (RFA), 2008). In Botswana, food cropping takes place on 96,266 ha, whereas 228,733 ha remains idle (idle land estimated to be 70% as compared to that of utilized land of 30%). The lack of policies to guide biofuel production has resulted in most of the energy projects in Tanzania being located on land suitable for food production (likely to make the country vulnerable to food insecurity).

Studies reveal that the production of biofuels may adversely affect food availability if productive resources (land, labor, water, nutrients etc.) are switched from the production of food to that of biofuels. In India, about 60% of the population is associated with agriculture and related activities. At least half reside in rural areas and are either marginal farmers or landless labourers. The country's available agricultural land is proving insufficient to grow food grains at an affordable price (soil erosion, nutrient depletion, lower productivity and dependence on monsoon) and incentives to switch land use from food crops to fuel crops may severely upset food economics (farmers see more profits in energy crops as compared to food crops). This growing emphasis may shift the balance where biofuels will start competing for land and water and thus initiate the food vs. fuel security debate (biofuels should not affect yield of main crops or threaten food security) (Kumar et al,2012).

The choice of feedstock grown also impacts food availability; for example Jatropha is not a food crop, however it's a strong candidate in

many developing countries for biofuel production and may indirectly compete with food production due to the use of resources such as fertilizers, water and land. Using idle, impoverished, marginal or set aside land for its production is good for food security and prevents the displacement of food crops from fertile agricultural land (reduce associated negative impacts of land use change). Other commentators argue that the food-fuel conflict could be minimized by intercropping food and energy crops as is currently the case in Mali and Zambia (Green, 2009; Janssen et al., 2009).

Jatropha can be cropped along with Lentil/Linseed as Rabi crop and along with Mungbean/Cowpea as Kharif crop. It can also be planted in combination with a shaded perennial crop system i.e. Turmeric/Ginger. It can be cultivated as Agri-Horti-Silviculture with Ber, Brinjal and Mothbean or Karonda, Okra and Clusterbean or Guava and Cucurbits. In Botswana, however, experienced commercial farmers were against the practice of intercropping with Jatropha (they felt that Jatropha would compete with food crops for nutrients, therefore resulting in low crop yields). It has even been suggested that Jatropha be planted separately to avoid competition with food crops. In depth research on agronomic, socio-economic and environmental aspects of intercropping energy and food crops are required before these questions could be answered.

Approximately 95% of vegetable oils used in biodiesel production come from edible oil palm, soybean and rapeseed oils (Leung et al., 2010). Global growth in crop-based biofuel production has expanded the demand for commodities such as corn, oil seeds and sugarcane beyond the traditional food, feed, fiber and industrial food-processing uses. Higher prices for these commodities have benefitted farmers and generated employment. This shift, together with increasing agricultural production costs, has negatively impacted the supply and price of the commodities available on international markets.

The concern that food crops become fuel, leaving the world's poorest inhabitants hungry, is a complex problem and the answer depends on from which side of the fence the argument is made. Rising food prices are fueling the debate as to the sustainability of crop based energy production in countries struggling with poverty and food scarcity. Some experts argue that as biofuel production levels rise, earnings are expected to increase along with employment in the sector and the predicted increases in food prices could be offset by higher incomes and biomass prices. The success for such an argument hinges on how these gains are distributed amongst the various stakeholders (producers and consumers) and requires investigation to understand its implications and impact.

So far, evidence has shown that biofuel programs have raised the price of certain foods. A case in point is Peru, where most of the country's biodiesel is made from oil palm; of national concern is that the nascent biodiesel initiatives will negatively impact palm oil volumes destined for food production, increasing its food import bill for edible oils (not self-sufficient in edible oils). The emphasis must be on satisfying demand for food instead of fuel. Government initiatives aimed at productivity improvements in the vegetable oil sector have led to increased oil palm acreage and utilize impoverished and deforested tracts of land in the Amazon basin. The Peruvian government's aim is to become self-sufficient in the production of edible oil and generate a surplus (excess diverted to the biodiesel sector), thereby avoiding competition between food and fuel markets.

In Europe, rapeseed oil, a major ingredient in food preparation, is also used for making biodiesel. Ethanol production in the US and Brazil has increased the price of corn and sugar globally. The longer term impact on vegetable oil is expected to be at least a 20% increase in the price by 2014 due to the combined effect of blending mandates for the US, EU and Canada and it is expected that corn prices will rise 70% above year 2000 prices by the year 2020. Grain prices have impacted food security and affect the poor and many developing nations. One is example of this is in Sub-Saharan Africa when in the year 2000 grain imports averaged 33%, reaching high dependency levels of more than 80% in Sudan, Gambia and Zambia. This trend will prohibit countries from importing food and aggravate the food security problem (hunger and malnutrition).

Increases in demand and prices have been an attempt by governments to help biofuel programs get established and to protect farmers from excessively low prices; it is expected that as biofuel programs expand, incomes will improve and benefit impoverished and vulnerable farming communities. Moreover if biofuels end up absorbing much of the agricultural overproduction from the developed world, commodity dumping on world markets could be avoided to the benefit of farmers in the developing world (spared artificially low prices). Small-scale labor-intensive farms for growing biomass will benefit poor farmers (by keeping them employed and able to afford food throughout the year). The industrialized growing of biomass in monocultures dominated by wealthy producers could drive small farmers from their land. In Brazil, the early years of the *Proalcool* programme did result in food shortages in the Northeast; the government's current biodiesel initiatives are specifically targeted at poverty reduction (provide an avenue for the poorest to sell their tree oil crops and aim to improve the economic conditions of these people) (Kojima and Johnson, 2005).

Advanced cellulosic technologies (biotechnology, enzymes and organisms) and thermochemical (gasification, pyrolysis, Fischer-Tropsch synthesis) hold the promise to take the pressure off conventional sugar, starch and oil biomass sources, particularly as biofuel demand ramps up and places strain on food crops and productive land. The likelihood for such theories working will depend on whether or not yields can be increased further, population expansion, the extent to which meat and dairy products become mainstay and the fuel efficiency of vehicles. The central cause for food scarcity is usually economic inequality and food distribution, since the poorest are unable to afford when the prices are set by the wealthier producers. Can biofuel programs help to reduce some of these inequalities? Food insecure regions with their vulnerable populations might remain unable to purchase food at these prices despite production capacity and availability.

5.9 Infrastructure Requirements

Although the focus at present is on crop-based ethanol and biodiesel, considerable government and private company investments indicate a future biofuel mix consisting of alcohols from high-yield cellulosic materials and biodiesel derived from diverse sources, including algae. To deliver the projected volumes of biofuels (Sridhar et al., 2010), significant investments in infrastructure for transportation, intermediate storage, blending and distribution is needed in many countries. Even though there are risks in biofuel development, there is considerable ongoing debate regarding the sustainability of different biofuels in different regions of the world, but there is also the need to focus on the infrastructure risks (Sridhar et al., 2010).

The biofuel supply chain consists of a network of biomass producers, biorefineries, storage facilities, blending stations and end users. To compete effectively, a robust, reliable and sustainable supply chain is essential. However, uncertainties exist and include, raw material supply and price, finished goods demand and price, pre-treatment, production and yield and transportation. To achieve optimal performance, contingencies and sustainability issues (economic, social and environmental factors) must be considered for supply chain optimization. As biofuel production ramps up, infrastructure development will need to be expanded to keep pace. The basic infrastructure requirements that need to be addressed for ethanol and biodiesel will include (1) distributed versus centralized production (2) transportation of feedstock and finished products (truck, rail, barge, ship

and pipeline) and (3) investment in new plants, storage capacity, vehicle fuelling stations and associated safety measures.

Biofuel volumes are lower and more decentralized when compared to petroleum refineries. In the case of biodiesel, a wide range of plant and animal feedstock can be used. As a result, production facilities are dispersed (raw oil extracted at one location and sent to another for processing). Ethanol production on the other hand tends to be more concentrated geographically and is distributed amongst different facilities within a specific production region (in the US, corn-belt states of Iowa, Illinois, Minnesota, Nebraska and South Dakota and in Brazil the state of Sao Paulo). Despite being spatially concentrated in specific regions, ethanol production in Brazil and the US is decentralized among different plants due to transportation and handling costs which place economic limits on the size of processing plants (unprocessed biomass is bulky, transport and logistics play an important role in location and overall biofuel economics).

The bulky nature of biomass also restricts available areas for handling at busy ports. Pre-treatment technologies for compacting bulky biomass at a low cost for transport and handling continue to be a challenge. Densification technology has improved, however, it is only suited for certain types of biomass e.g. woodchips (final density per cubic meter is still far less than oil given the nature of biomass). Thermal decomposition processes such as pyrolysis and torrefaction are being investigated as possible pre-treatment options, but still need to be demonstrated on a commercial scale. In the case of the import of liquid biofuels (e.g., bioethanol, vegetable oils, biodiesel), this is not an issue, as the energy density of these biofuels is relatively high. Feedstock transportation cost depends on distance and time for haulage and time for loading and unloading (Noon et al, 1996). Rail transport is expected to be cheaper, however, trucks can access more sites than a railroad or a waterway. Studies of transport costs for the different types of biomass need to be undertaken.

5.10 Transport, Storage and Delivery

World ethanol production was estimated at 38.2B liters in 2004 and escalated to 60B liters by 2010 (Kaltner et al, 2005). However, for the production and use of biofuels to become prevalent, infrastructure for transport, storage, distribution and delivery must be developed. The cost required for these steps depends upon the type of fuel and vehicle and existing transport infrastructure to move feedstock and fuel around. Ethanol, ETBE, biodiesel and synthetic diesel (liquid fuels similar to petro-fuels) have lower

refueling station costs than gaseous fuels as H_2 or CNG. Biogas could be upgraded to pipeline quality (removal of siloxane, carbon dioxide, water, hydrogen sulfide) and compressed for use in vehicles. The cost for vehicles to be retrofitted to run on gaseous fuels must be factored in and compared to the convenience of using ethanol or biodiesel blends with minimal modifications. In contrast to biogas, it will probably be easier to use an existing pump and storage tank or install a new fuelling system if biofuel cannot be accommodated at a service station.

Pure ethanol is used in tropical and sub-tropical climates whereas E85 (85% ethanol and 15% gasoline is used in colder climates such as the US and the EU). Germany has proven that pure biodiesel fuel (B100) can be used in existing diesel engines with minor modifications and with no fuel tax on biodiesel more than 1500 refueling stations now sell the fuel. Questions have arisen as to whether or not B100 will be compatible to new particulate and NO_X standards (EURO V regulations).

Brazil is building infrastructure to export ethanol internationally (investments in the construction of larger marine terminals, greater storage capacity as well as the construction of pipelines to minimize transportation costs). Such infrastructure will facilitate export demands by connecting storage facilities in the state of São Paulo with ports in Rio de Janiero and São Sebastião. The increased capacity of the two ports is expected to reach 4M m^3 per year. The Brazilian oil company Petrobras increased their export capacity from 2 billion liters in 2007 to 4 billion liters in 2009 and then to 9.4 billion liters 2012. Petrobras has extensive experience with ethanol logistics, including pipeline transport and is developing large scale biofuels distribution infrastructure. Part of the ethanol consumed domestically in Brazil is mixed with gasoline and the remainder used as a 'neat' fuel. The ethanol produced in sugar mills and distilleries need to be transported to terminals that distribute the gasoline-ethanol mix and the neat fuel ethanol to the retail market. Although the railroad is more cost effective than road transport to transfer ethanol between producers and distribution terminals, this option is seldom available due to the limited availability of rail transport and the significant upfront investments required (distribution is done primarily by truck). In the US, ethanol consumption has been raised from 6 billion liters (2000) to approximately 50 billion liters (2010) (800% increase, approximately equivalent to 10% v/v of the gasoline supply in the United States). This has come from 204 ethanol biorefineries across 29 states (9 new facilities under construction) (RFA, 2011). Numerous states and municipalities are helping to finance the construction and upgrade of the transport infrastructure between bioethanol plants and cities.

Although pipeline transport is the cheapest way to transport liquid fuels, biofuels face several challenges in this regard. Phase separation can occur if water gets into the pipelines or fuel. Rather than being mixed with gasoline, the ethanol pulls itself out of the blend, creating a separated ethanol water layer (concern in cold weather as phase separation occurs more readily in lower temperatures and possibility of freezing). When 'neat' ethanol is to be transported, if it contains a small amount of water, the water component can contribute to corrosion in steel pipelines. Biodiesel is easier to transport and store than ethanol and can use the same infrastructure as diesel.

However because of the smaller volumes it is usually transported by truck which is not as economical as the pipeline system. Transportation costs for biodiesel in the US can be as high as 440 USD per 1000 liters (Van Dyne and Blasé, 1998). Nineteen hundred (1900) refueling stations in Germany sell pure biodiesel in the form of RME 100 and most of the petrodiesel sold in Germany contains a blend of 2% RME (aim to increase to 5% RME over the next 4 years). Some competition is anticipated between refiners and refueling stations, however production increases is expected to keep pace to meet demand. With the phasing in of ultra-low sulfur fuel, a concern is that pipelines and storage tanks used to transport petro-fuels previously may have a buildup of sulfur residues on their surface that could be freed up by the solvent action of biodiesel (raising the sulfur content of diesel-biodiesel blends above allowable levels). An assessment is needed to determine the potential severity of the problem and possible countermeasures.

Global trade in biomass and biofuels will warrant suitable infrastructure, particularly by sea. The availability of vessels, international shipping rates and dedicated tankers for bioethanol and biodiesel will drive energy and transport costs and economic viability. Harbors and terminals suitable to handle large biomass streams will need to be constructed to facilitate imports and exports in certain regions. The most favorable situation is when the end user's facility is close to the harbor avoiding additional transport by trucks. Overland transport (truck or train) may also attract higher costs and influence the overall fossil energy balance for the biofuel and total biomass costs. In Brazil, new sugarcane plantations planned for the Centre-West of the country could be severely constrained by lack of road infrastructure to transport bioethanol to the demand centers (either domestically or for export).

The bioenergy trade for biomass (chips, logs and bales), intermediate energy carriers (bio-oil, charcoal) and high quality energy carriers (ethanol, methanol, Fischer-Tropsch liquids and hydrogen) must take into

consideration the production method for biomass, the type of transport and the choice of pre-treatment operations. Studies have revealed that for transporting raw or processed biomass, the most favorable approach is to have it in a form having a high energy density (pellets, logs and liquid carriers as opposed to wood chips). To some extent, the international transport of biomass is already undertaken by large pulp and paper complexes that import wood globally and this system could be used as a model.

The benefits for society of biofuels for the transport sector depend on the ways in which biomass is grown and converted to biofuels, i.e. the biofuels system as a whole (IPIECA, 2009). Benefits can include the improvement of energy security, rural development and the reduction of greenhouse gas emissions.

Biomass is a renewable, but limited resource which, even in optimistic scenarios considering the current technology, can only be expected to cover a modest fraction of the energy needs of the world. If emissions of greenhouse gases are to be reduced as the prime objective then government policy instruments should ensure that biomass is used and managed where it maximizes avoidance of greenhouse gases, or where it is the best available alternative to replace carbon intensive energy products. This can only be achieved through assessing and comparing the different possible ways to manage and use the available bioresources. These may be (or even, will be) different from country to country and region to region; this should be recognized when regional mandates for biofuel utilization are being considered.

The large-scale development of biofuels raises a number of concerns relating to competition with food and pressure on land resources, potentially leading to reduction in food availability, increased food prices and encroachment on sensitive land areas and forests. In some cases, when biofuel production causes the clearing of high carbon content land, substantial emissions of carbon dioxide can be produced that may impact the greenhouse gas emission benefits of a biofuels system for decades.

Many of these effects can only be realistically assessed by the management of the performance of specific biofuel systems as well as the management of the effects outside the boundaries of a biofuel system.

5.11 Government Policies and Regulations

Wide ranging policy strategies are vital for the development of a strong and sustainable biofuel industry, both domestically and globally (WEC, 2010). Blending mandates and exemptions from fuel taxes are some common

policies to support biofuel initiatives. Other instruments such as loan guarantees, tax incentives for the agricultural and forestry sector, consumers and manufacturers, preferential government purchasing policies are also initiatives. In addition, research, development and demonstration funding for conventional and next generation biofuels technologies are being used more frequently. As discussed, one of the drivers for governments to institute a biofuel policy is to aid in the economic development of rural areas, create jobs and to bring welfare benefits to impoverished communities. Otherwise if left to the private sector, purely commercial interests will gravitate towards economies of scale that provide the best ROI to their shareholders. Cooperation between public and private interests will help to ensure that small producers along the value chain do benefit from income, employment, technology and capacity building opportunities.

As discussed elsewhere (Chapter 3 Biofuel Policies, Section 3.4 Standards and Certification Schemes and 3.5 International Trade) industrialized countries are well poised to be solution providers to emerging countries who wish to promote a sustainable biofuels development programme (formulating strategy, technical assistance, navigating standards and certification schemes, leading complex trade negotiations, financing, logistics, access to markets in developed countries).

Furthermore, the promotion, management and certification of sustainable biofuels are complex and they require a well-coordinated, multi-faceted and credible approach. While governmental mandates, international standards and certification program are instrumental in promoting the responsible production of sustainable biofuels, they are susceptible to fraud if not managed correctly and can disrupt the supply chain, increase costs and inflate bureaucracy (IPIECA, 2010).

Fuels are a commodity whose individual units are capable of mutual substitution and are freely exchanged or swapped as a tradable commodity. Biofuels can be produced from numerous feedstocks from various regions around the world and can involve the mixing of different feedstocks to produce a batch of biofuel. Each economic operator of the supply chain, from buying agent to fuel supplier, has an interest in creating the best quality product at the lowest cost, which involves the purchase of feedstocks, bio-oils or biofuels from a number of undisclosed suppliers. The fungible nature of biofuels, the complexity of the supply chain, the volatility of the market and the commercial nature of the business transactions involved, necessitate a credible accounting system.

A *chain-of-custody* (CoC) is a management system which involves the chronological physical or electronic documentation – and/or paper trail – showing the acceptance/purchase, custody, control, transfer and

disposition of a product or associated sustainable attributes. An effective *chain-of-custody* system should minimize costs, limit distraction from the core business of each economic operator and ensure a high level of credibility and integrity, as well as preserve the flow of fuel trade and infrastructure. It is also widely accepted that any benefits or burdens associated with a *chain-of-custody* system or the certified product it is tracking should be shared equally among all supply chain actors and should not disadvantage small-scale economic operators.

In addition, policies must be flexible to cope with the long term development of alternative feedstock energy crop sources and conversion technologies (next generation biofuels). It could be argued that given the current state of technology and the uncertainty remaining about future breakthroughs that could potentially make some 2nd generation biofuels cost competitive, emphasis should be on the most promising ones (differentially incentivize production pathways with greater promise). The conundrum would be if to exploit current technologies to meet RE targets or to wait for the next generation of technologies before scaling up. Further study would afford a more complete and comprehensive picture of a biofuel potential and the potential impact which would help in formulating a more comprehensive energy strategy.

Policy makers will need to harness the capacity of biofuels that simultaneously advance multiple goals (rural development, climate change, regional and international developments (policies and trade), energy provision, food vs. fuel, sustainability criteria, standards and certification schemes). As an example, support of biofuels that do not comply with international standards (e.g., on quality or sustainability criteria) would hardly result in the deployment of an industry able to expand beyond some local or domestic markets (Carriquiry et al, 2011).

In fact, many barriers that today constrain world trade in biofuels can be removed by introducing international specifications and standards. Not only must properties of final biofuels products be managed and harmonized but there also must be methodologies for measuring these properties. International bodies such as the American Society for Testing and Materials (ASTM) and the International Standards Organization (ISO) are the appropriate forums to discuss this subject with the participation of all stakeholders.

Subsidies have been introduced to aid farmers in growing energy crops as an added source of income (Section 5.5 Subsidies). Biofuels also hold the promise to reduce oil imports and the associated security and economic costs. Governments that have ratified the Kyoto Protocol are also promoting biofuels as a way of meeting national or regional greenhouse gas emissions reduction targets. Governments must set out clear legal, fiscal and institutional

guidelines to encourage public and private sector participation and ensure that supply chains provide income and employment for small producers/laborers/processors and help to improve their livelihoods (especially in developing countries) etc. If advanced cellulosic technologies are to become mainstream, new policy instruments will need to be developed to facilitate their growth (research investments by the US DOE have led to a 30 fold reduction in the cost of enzymes used in cellulosic ethanol production, a major step towards commercialization). Researchers are also working on producing *co-products* (additional marketable products or added-value products) and fuels from a wide range of biomass feedstock and many countries are moving towards a more equitable and sustainable approach in their biomass planning processes (Chapter 2, Section 2.5 Impact Of Growing Biomass).

Finally, concerns over energy security, economic development and climate change are driving the development of biofuels as one of a number of possible alternatives to fossil fuels for helping to meet increasing global energy demands. Current methods of biofuel production have been associated with poor management leading to (1) harm to the environment, (2) threats to food security and prices and (3) human rights violations in the countries where they are grown. New types of biofuels, such as lignocellulose and algal biofuels, could help to reduce greenhouse gas emissions while avoiding the problems raised by current production methods. However, commercial-scale production is years away and management is already being put in place and not subject to bias one way or the other. This requires a framework to guide management policy making for biofuels and current biofuels targets should be replaced with a well-managed strategy that considers the wider consequences of biofuel production. Specific recommendations for management policy include attention to (1) human rights, (2) environmental sustainability, (3) climate change and (4) an equitable distribution of costs and benefits.

Strong government support for small producers in the form of legal, fiscal and institutional framework is required in developing nations for their nascent biofuel industries if they are to be sustainable and bring welfare benefits to rural areas. Public–private partnerships are necessary to ensure that supply chains generate income and employment for small producers and labourers. The private sector can play a critical role in technology transfer and related capacity building that could improve productivity. Developing countries will require technical assistance, policy formulation and financing for their nascent programs, however, for any biofuel production systems to go beyond the pilot-level and become viable in the long-term, there must be a demonstrated return on investment (even if subsidized) and a way of ensuring consistent levels of production and the availability of necessary feedstocks.

References

APEC. 2010. "A Study of Employment Opportunities from Biofuel Production in APEC Economies." Report No. APEC EWG 07/2008A. Asia-Pacific Economic Cooperation Secretariat, Singapore. Feburary.

Al-Riffai, P., Dimaranan, B. and Laborde, D. 2010. "Environmental Impact Study of the EU Biofuels Mandate." International Food Policy Institute (IFPRI), Directorate General for Trade, European Commission, Washington, DC. March.

Bastos Lima, M.G. 2012. "An Institutional Analysis of Biofuel Policies and their Social Implications: Lessons from Brazil, India and Indonesia." Occasional Paper Nine Social Dimensions of Green Economy and Sustainable Development. United Nations Research Institute for Social Development, Geneva, Switzerland.

Blanco Fonseca, M., Burrell, A., Gay, H., Henseler, M., Kavallari, A., M'Barek, R., Pérez Domínguez, I. and Tonini, A. 2010. "Impacts of the EU Biofuel Target on Agricultural Markets and Land Use: A Comparative Modeling Assessment." Report No. EUR 24449 EN. European Commission Joint Research Centre, Institute for Prospective Technological Studies, Seville, Spain.

Blom, M. and Solmar, C. 2009. "How to Socially Assess Biofuels: A Case Study of the UNEP/SETAC Code of Practice for Social- Economical LCA." Division of Quality and Environmental Management, Luleå University of Technology, Luleå, Sweden.

Carriquiry, A.M., Du, X. and Timilsina, R.G. 2011. *Second Generation Biofuels: Economics and Policies*. Energy Policy 39: 4222-4234.

Chege, K. 2007. "Biofuels: Africa New Oil." Science and Development Network. December.

Dale, V.H., Kline, K.L., Wiens, J. and Fargione, J. 2010. "Biofuels: Implications for Land Use and Biodiversity." Biofuels and Sustainability Reports, Ecological Society of America. Washington, DC.

Echols, M.A. 2009. "Biofuels Certification and the Law of the World Trade Organization." ICTSD Program on Agricultural Trade and Sustainable Development. International Centre for Trade and Sustainable Development (ICTSD), Geneva, Switzerland.

Elbehri, A., Segerstedt, A. and Liu, P. 2013. "Biofuels and the Sustainability Challenge: A Global Assessment of Sustainability Issues, Trends and Policies for Biofuels and Related Feedstocks." Trade and Markets Division, Food and Agriculture Organization of the United Nations, Rome.

Ewing, M. and Msangi, S. 2009. *Biofuels Production in Developing Countries: Assessing Tradeoffs In Welfare And Food Security*. Environmental Science and Policy, 12: 520-528.

Fritsche, U.R., Hünecke. K. and Wiegmann, K. 2005. "Criteria for Assessing Environmental, Economic and Social Aspects of Biofuels in Developing Countries." Öko Institut e.V., Darmstadt, Germany.

Harmer, T. 2009. "Biofuels Subsidies and The Law of the WTO." Issue Paper No. 20. ICTSD Program on Agricultural Trade and Sustainable Development. International Centre for Trade and Sustainable Development (ICTSD), Geneva, Switzerland.

IPIECA. 2009. "Biofuels, Sustainability and the Petroleum Industry." IPIECA, London, United Kingdom.

IPIECA. 2010. "Chain of Custody Options for Sustainable Biofuels." IPIECA, London, United Kingdom.

IPIECA. 2012. "The Biofuels and Water Nexus: Guidance Document for the Oil and Gas Industry." IPIECA, London, United Kingdom.

Jones, C. 2005. *Europe Adopts Biodiesel: Can an African Bean Crack Europe's Biodiesel Blockage?* Eco World. September 28.

Kaltner, F., Azevedo, G.F.P., Campos, I.A. and Mundim, A.O.F. 2005. "Biofuels for Transportation: Brazilian Potential and Implication for Sustainable Agriculture and Energy in the 21st Century." Prepared for the Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Rio de Janeiro, Brazil. November. Page 23.

Kim, H., Kim, S. and Dale, B. 2009. *Biofuels, land use change and greenhouse gas emissions: some unexplored variables.* Environmental Science and Technology, 43: 961-967.

Kojima, M. and Johnson, T. 2005. "Potential for Biofuels for Transport in Developing Countries." World Bank, Washington, DC. October

Kumar, S., Chaube, A. and Jain, S.K. *2012 Sustainability Issues for Promotion of Jatropha Biodiesel in Indian Scenario: A Review*. Renewable and Sustainable Energy Reviews 16: 1089-1098.

Leung, D.Y.C., Wu, X. and Leung, M.K.H. 2010. *A Review on Biodiesel Production Using Catalyzed Transesterification.* Applied Energy, 87: 1083-1095.

Meyer, S., Schmidhuber, J. and Barreiro-Hurlé, J. 2013. "Global Biofuel Trade: How Uncoordinated Biofuel Policy Fuels Resource Use and GHG Emissions." Issue Paper No. 48. International Centre for Trade and Sustainable Development (ICTSD), Geneva, Switzerland.

Noon C.E., Daly, M.J., Graham, R.L. and Zhan, F.B. "Transportation and Site Location Analysis for Regional Integrated Biomass Assessment (RIBA)." Proceedings. Bioenergy 1996 – The Seventh National Bioenergy Conference: Partnerships to Develop and Apply Biomass Technologies, Nashville, TN, 15-20 September. http://bioenergy.ornl.gov/papers/bioen96/noon1.html

NREL. 2000. Biomass for Sustainable Transportation and Use. National Renewable Energy Laboratory, Golden, Colorado. www.nrel.gov/docs/fy00osti/25876.pdf

NCB. 2011. "Biofuels: Ethical Issues. Nuffield Council on Bioethics." London, United Kingdom.

Osava, M. 2006. "The Time for Biofuels is Now." Energy Latin America. April.

OECD. 2008. Organisation for Economic Co-operation and Development) 2008): "Biofuel Support Policies: An Economic Assessment." Organization for Economic Co-operation and Development, Paris, France.

Pelkmans, L., Govaerts, L. and Kessels, K. 2008. "Inventory of biofuel policy measures and their impact on the market." Report of ELOBIO Subtasks 2.1-2.2. ELOBI Petten, Netherlands. http://www.elobio.eu/fileadmin/elobio/user/docs/Elobio_D2_1_PolicyInventory.pdf , accessed August 9, 2013.

Quintero, J.A., Felix, E.R., Rincón, L.E., Crisspín, M., Baca, J.F., Khwaja, Y. and Cardona, C.A. 2012. *Social and Techno-Economic Analysis of Biodiesel Production in Peru.* Energy Policy 43: 427-435.

Rajagopal, D. and Zilberman, D. 2007. "Review of Environmental, Economic and Policy Aspects of Biofuels." Policy Research Working Paper No. 4341. Development Research Group, Sustainable Rural and Urban Development Team, The World Bank, Washington, DC.

RFA. 2005. Home-grown for the Homeland. Ethanol Industry Outlook 2005, Washington, DC. http://www.ethanolrfa.org/objects/pdf/outlook/outlook_2005.pdf

RFA. Renewable Fuels Association. 2011. Building Bridges to a More Sustainable Future: Ethanol Industry Outlook 2011, Washington, DC. http://www.ethanolrfa.org/page//2011%20RFA%20Ethanol%20Industry%20Outlook.pdf?nocdn=1 accessed 6 June 2011.

Rutz, D. and Janssen, R. 2008. *Biofuel Technology Handbook*. WIP Renewable Energies, Munich, Germany.

Sims, R., Taylor, M. and Saddler, J. 2008. "From 1st- 2nd Generation Biofuel Technologies: An Overview of Current RD&D Activities." OECD/IEA. International Energy Agency, Paris, France.

Sridhar, N. Gui, F., Beavers, J.A. and James, J. 2010. "Biofuel Infrastructures: managing an Uncertain Future." Research and Innovation, Position Paper 03-2010. Det Norske Veritas, Høvik, Norway.

Teixeira Coelho, S. 2005. "Biofuels – Advantages and Trade Barriers." Proceedings. United Nations Conference on Trade and Development, United Nations, New York.

Trindade, S.C. 2005a. "Global Biofuels Trade." Proceedings. XV International Symposium on Alcohol Fuels. Alcohol Fuels in Sustainable transportation: Alcohols and Other Renewable Fuels. San Diego, California. September 26-28.

Trindade, S.C. 2005b. "Brazil, the Driver of Sustainable Markets for Fuel Ethanol – Assessing the Biofuels Option." Proceedings. Global Biofuels Trade. International Energy Agency, Paris France. June 20-21.

UNCTD. 2009. "The Biofuels Market: Current Situation and Alternative Scenarios." Report no. UNCTAD/DITC/BCC/2009/1. United Nations Conference on Trade and Development, United Nations, New York.

US DOE and EERE (2006) Biofuels and the Economy. http://permanent.access.gpo.gov/websites/www.ott.doe.gov/biofuels/economics.html;

Van Dyne, D.L. and Blasé, M.G. 1998. "Cheaper biodiesel through a reduction in transaction costs," in Proceedings of Bioenergy 1998: Expanding Bioenergy Partnerships. http://www.biodiesel.org/resources/reportsdatabase/reports/gen/19981001_gen-109.pdf

Wachira, G. 2009) *Kenya: Country Needs Sustainable Biofuel Projects.* Business Daily (Nairobi). November.

Wilcox 2005 'Energy outlook: Impacts on biofuels and implications for the farm sector', Presentation to 2005 http://www.fapri.missouri.edu/outreach/presentations/2005/cropmang_dec05.pdf

WEC. 2010. "Biofuels: Policies, Standards and Technologies." World Energy council, London, United Kingdom.

World Bank. (2011). State and trends of carbon market 2011. Washington, DC: World Bank. www. worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/EXTCARBONFINANCE/0,,contentMDK:22928492~pagePK:64168445~piPK:64168309~theSitePK:4125853,00.html, accessed August 9, 2013.

Worldwatch Institute. 2006. "Biofuels for Transport: Global Potential and Implications for Energy and Agriculture", prepared by Worldwatch Institute for the German Ministry of Food, Agriculture and Consumer Protection (BMELV) in coordination with the German Agency for Technical Cooperation (GTZ) and the German Agency of Renewable Resources (FNR), published by Earthscan, London, United Kingdom.

6

The Future of Biofuels

6.1 Introduction

A biofuel is a fuel that contains energy from geologically recent time by carbon fixation and is produced from living organisms (Chapter 1). These fuels are made by a conversion of biomass (typically plants or plant-derived materials). Biomass can be converted to biofuels in three different ways: (1) thermal conversion, (2) chemical conversion, or (3) biochemical conversion, which result in solid, liquid or gaseous fuel products.

Next-generation biofuels refer to biofuels made using advanced technologies that greatly expand the potential to use widely available secondary and tertiary biomass sources including woody biomass and wood waste, crop residues, dedicated energy crops such as switchgrass, miscanthus, canary reed grass, municipal solid waste and algae. In fact, the production of second-generation biofuels is focused on the large-scale development of these concepts (Farrell et al., 2006; Robertson et al., 2008; Mandil and Shihab-Eldin, 2010). This involves the use of advanced technology to break down lignocellulosic plant matter into sugar products which can then be distilled into ethanol fuel, or the gasification of biomass followed by the conversion of gas to liquid (the Fischer-Tropsch process) within a

biorefinery or as part of a conventional petroleum refinery (Speight, 2008; Chadeesingh, 2011; Speight, 2011a, 2011b). Lignocellulosic bioenergy crops are typically woody and herbaceous perennial species (Hill et al., 2007). Switchgrass, Miscanthus, wood plantations (e.g., poplar), as well as forestry and agricultural waste products may all be converted to biofuel using these advanced technologies. These processes typically yield more energy than traditional biofuel (Heaton et al. 2008), but large-scale production is still under development.

Furthermore, algae (in theory) are easy to cultivate, can grow with limited attention almost anywhere (as anyone with a poorly ventilated bathroom can attest to) and can make use of water that is unfit for human consumption. Algae growth rates are highest when the concentration of algae in a solution is low, yet oil yields may be higher for high algae concentrations. In turn, the separation of oil from the algae-water slurries is energy intensive and expensive and an ideal algae cultivation unit design remains uncertain. Overall, extensive research and development will be required to bring costs down and make scalable, consistent processes for algal biofuel production. As algae become more efficient at producing these desirable oils and the extraction and cultivation methods decrease in cost, the opportunity to utilize algae for large-scale diesel fuel production becomes realistic (Chisti 2008; Herro 2008; Jenner, 2008; Patil et al., 2008; Wang et al., 2008). As a result, some next-generation biofuels such as biobutanol and green gasoline and green diesel may use traditional feedstocks such as sugar beets, corn, sugarcane, animal fats and vegetable oils.

Managing next generation biofuels and environmental consequences is extremely important and it must not be recognized as a simple-one-step process to move into the higher generation of feedstocks. As with all biofuels, next-generation biofuels must be compatible with future transportation infrastructure and be derived from environmentally sustainable resources that do not compete with food crops and also fit within various refining scenarios that tend to change fuel composition, depending upon the feedstocks (Sims et al., 2008; Speight, 2008; 2011b, 2014). Many bacterial species have unique properties advantageous to the production of such next-generation fuels (Gronenberg et al., 2013). However, no single species possesses all characteristics necessary to make high quantities of fuels from plant waste or from carbon dioxide. Species containing a subset of the desired characteristics are used as starting points for engineering organisms with all desired attributes. The metabolic engineering of model organisms has yielded a high production of advanced fuels, including alcohols, isoprenoids and fatty acid derivatives.

The near-term challenges facing the next-generation biofuel sector include (1) reducing high capital-investment and production costs, (2) acquiring sufficient financial resources for pre-commercial development and (3) developing new feedstock supply arrangements. Success has been achieved in the last decade in reducing costs though conservative management but private financial resources supporting the sector may have slowed their increase in 2009 as the recession reduced energy demand and investor interest in alternative fuels. In the United States, public-sector resources helped to bolster private resources through the Federal stimulus bill (ARRA, 2009) and other government programs for next-generation projects.

The role for agriculture could be substantial as the next-generation sector expands. A key challenge will be the development of supply arrangements for agricultural residues, energy crops and other feedstocks. The use of existing streams of biomass, such as wood waste and municipal solid waste, may provide some early advantages for non-agricultural biomass until supply arrangements for agricultural residues and dedicated energy crops are developed.

Another important issue will be *managing risk*. The capital-investment and production costs of next-generation biofuels are currently projected to be high (Coyle, 2010). It is an emerging sector and untested in the market. Once up and running, companies will depend on the delivery of large quantities of biomass, subject in some cases to the vagaries of weather. They will have to deal with the limited market for ethanol as a gasoline additive as the E10 *blend wall* is approached as a gasoline substitute and the market for E85 slowly develops.

These elements of risk and uncertainty will cause investors in new operations to strive for maximum flexibility in terms of the kinds of feedstock they are capable of processing and for the kinds of biofuels that are least affected by constraints in the ethanol market. Developing the capacity to use multiple feedstocks and to produce bio-based fuels that are equivalent to fossil fuels and that can be used in current vehicles without limit and distributed seamlessly in the existing transportation sector may become the least risky business model to pursue.

As with *1st generation biofuels*, there are three significant conversion pathways for producing next-generation biofuels, but with subtle differences from the production of the 1st generation biofuels: (1) biochemical hydrolysis, (2) gasification and (3) pyrolysis (Speight, 2008, 2011a). Each pathway involves the breaking down of biomass into intermediate compounds – sugars, syngas and bio oil – and then converting them into various fuels, primarily ethanol, but also biobutanol and petroleum-equivalent fuels. In some cases, a hybrid approach will be used in which biochemical and

thermochemical processes will be employed. While most next-generation companies are using or planning to use nonfood feedstocks, there are some that may use first-generation feedstocks, such as corn, sugarcane and sugar beets, for the production of biobutanol and petroleum-equivalent fuels. The primary development focus for algae-based fuels is reducing the production costs of the algae feedstock.

In the hydrolysis process, the biomass is physically or chemically pretreated to modify the chemical structure and to separate the sugar-containing components, cellulose (6-carbon sugar) and hemicellulose (5-carbon), from the non-sugar lignin. Enzymatic or acid hydrolysis is then used to break down the cellulose into simple sugars. Companies are experimenting with different combinations of pretreatments, enzymes and acids to reduce processing costs. The sugars are fermented using yeast or bacteria to produce a dilute solution of ethanol that is then distilled to fuel-grade quality (>95% pure ethanol), similar to the first-generation process.

Like ethanol, biobutanol is a product of fermentation but has higher energy content. Microbes are genetically modified to produce an alcohol with a longer hydrocarbon chain (four versus two carbons) than ethanol, raising its energy content above that of ethanol and closer to gasoline. Being more similar to gasoline, biobutanol can be more easily blended with gasoline and transported by pipeline than ethanol. One such process can be used to convert sugars (from either cellulosic sources or first-generation feedstocks like sugarcane and corn) using catalysts to produce hydrocarbons. Another process replaces natural genes with synthetic ones in microorganisms that convert sugars, not into alcohols, but directly into diesel, gasoline, or jet fuel. There is also a process in which genetically engineered algae are used to convert carbon dioxide directly into hydrocarbons. The product oil has a similar composition to lower-to-mid-range-boiling petroleum fractions and can be refined into gasoline, diesel and jet fuel (Coyle, 2010).

In the gasification process, biomass is heated to a high temperature (approximately 800°C, 1470°F) with limited oxygen (Chadeesingh, 2011; Speight, 2011a, 2013a, 2013b). The biomass breaks down into carbon monoxide (CO), hydrogen (H_2) and carbon dioxide (CO_2). Carbon monoxide and hydrogen are combined to form synthesis gas (syngas), which is cleaned, cooled and either metabolized by bacteria and converted to ethanol or used as a feedstock for Fischer-Tropsch synthesis (Chadeesingh, 2011) in which the syngas undergoes a catalytic reaction to produce liquid hydrocarbons of various types. In the pyrolysis process, the biomass feedstock is heated to a lower temperature in the absence of oxygen to produce

bio oil, bio-char (a charcoal-like) and pyrolysis vapors (Speight, 2011a). The bio-oil is then refined to produce various petroleum-equivalent fuels.

A new way of looking at biofuel production is through the use of algae (Coyle, 2010). Algae in enclosed bioreactors (tubes, plastic bags, flat tanks) or in large open ponds have a potentially very high biofuel yield per acre. The algae are fed carbon dioxide (CO_2), in some cases from nearby heavy carbon dioxide-emitters such as coal-fired powered plants, cement kilns, or breweries (Coyle, 2010; Speight, 2013b). The algae are separated from the water by centrifuge or other means and the oil is extracted using a solvent. The oil is then processed into biodiesel, using first-generation technology. In addition, an old technology that has been revisited is the application of hydroprocessing technology to the production of biofuels. Hydroprocessing technology is used to convert animal fats and vegetable oils into a petroleum-equivalent fuel very similar to diesel fuel (Speight, 2011a, 2014). Catalytic depolymerization involves the breaking down of feedstock molecules more directly into biomass-based diesel.

Perhaps the final challenge to the production of next-generation biofuel is the development of arrangements to assure a steady year-round supply of biomass to the production site (the biorefinery). Access to low-cost feedstock is critical to the commercial prospects of next-generation companies, particularly given their high capital and conversion costs. Feedstock accounts for more than one-third of estimated cellulosic ethanol production costs. When fully commercialized, companies will require vast amounts of the bulky material to be delivered and stored at the processing plant. Biomass producers will need incentives to commit to sustained production of new feedstocks (Coyle, 2010).

6.2 Next Generation Biofuels

The beginning path to biofuels started with what is now known as conventional biofuels (1st Generation), which refers to fuel made from sugar, starch or vegetable oil. Bioethanol is the most common biofuel and is produced by fermenting plant sugars into ethanol. This technology has received much attention in the United States, Brazil and Canada, countries where corn and sugarcane are grown at a relatively low cost and where there is a strong political will to promote biofuels. Biodiesel is also a relatively common biofuel and demand is growing due to favorable legislation, especially in North America and Europe. It is produced from plant oils or sometimes waste oil. Furthermore, in many countries, gasoline is blended with up to 10% v/v ethanol.

The 2nd Generation biofuels refers to fuel made from lignocellulosic biomass such as woody biomass or agricultural waste. Second generation biofuels address some of the concerns about the sustainability of feedstocks. One of the challenges with lignocellulosic biomass is that the sugars are locked up in more complex carbohydrates (hemicellulose and cellulose), which can make it more difficult to break down for fermentation. A number of second generation technologies exist including thermochemical processes such as gasification, pyrolysis and torrefaction and biochemical routes using a pretreatment step such as ionic liquids, a strong acid and/or enzymes to accelerate the hydrolysis process. This class of biofuels addresses some of the concerns around biofuel such as carbon balance, land use and non-food based feedstocks (Speight, 2011a).

The 3rd Generation biofuels (*advanced biofuels*) are fuels derived from algae and bacteria. This generation of biofuels is based on biological processes and is an area of intense research and development. Many species of algae naturally produce low levels of long chain fatty acids when they are stressed and algae species can be screened and/or modified to increase the production yields of long chain fatty acids. Some of the cutting edge research around maximizing algae growth and oil production involve treating algae with common antioxidants which has demonstrated increases in oil production by as much as 85%. Additionally, through synthetic biology, organisms such as e-coli bacteria can be manipulated to secrete hydrocarbons using sugar as a feedstock.

However, many uncertainties continue to exist in the biofuel supply chain such as the security of biomass supply, the demand for fuels, processing issues (pre-treatment, production and yield), cost and transportation (there is a wide variability in feedstock, conversion technologies and end uses). To date, there are no large-scale production facilities for 2nd generation biofuels and the production technologies will in large part be driven by the characteristics of the biomass available for processing (agricultural plants, wood grown in forests, waste residues (farm, agricultural, field, forest) from the processing or use of these resources).

While there is enormous potential, cost is a major barrier to commercial production in the near-to-medium-term. While there is enormous potential for conversion of these polymers into recoverable base chemicals, cost is a major barrier to commercial production in the near-to-medium-term. Its potential will only be realized if it can be produced economically and at costs competitive with fossil fuels. In fact, cellulosic ethanol was 2 to 3 times higher than the current price of gasoline on an energy equivalent basis and the median cost (across the studies reviewed) of biodiesel produced from microalgae was 7x higher than the current price of diesel

(Carriquiry et al., 2011). For cellulosic ethanol, biomass conversion costs must remain the focus for savings through strong research and development programs whereas feedstock cost is the main issue for biodiesel. The potential feedstocks (lignocellulosic and biodiesel) for 2nd generation biofuels are discussed elsewhere in this book (Chapter 1). The choice for energy crops, research on crop selection and consensus from stakeholders, development and processing must be carefully thought through for successful implementation.

Given current technology, 2nd and 3rd generation biofuels will come at a very high capital cost, over 5x that of similar capacity starch ethanol plants. Capital investment for cellulose based ethanol production is estimated at USD 1.06 - $1.48/L (annual capacity) and operation costs between $0.35 - $0.45/L (depending on the feedstock and corresponding technologies) (Carriquiry et al., 2011). As conversion technologies improve, capital investment and operating cost are expected to decrease in the vicinity of $0.95 – $1.27/L and $0.11 - $0.25/L respectively (Hamelinck et al., 2005). The high cost and financial risk associated with 2nd and 3rd generation biofuels negatively impact the rate at which new conversion facilities will be constructed and support from government will bring confidence to the market and overcome early commercialization barriers (as they need to be cost competitive with conventional fuels). Given the variation in 2nd and 3rd generation feedstock costs (approximately 32 to 52% of production cost) Carriquiry et al., 2011 provided detailed cost treatment for microalgae, lignocellulose and jatropha; it is expected that production costs will also be wide ranging.

Much progress has been made in the policies related to production of first-generation ethanol and biodiesel, second-generation cellulosic ethanol and third-generation algae biofuels. However, research into 4th generation biofuel processes has not generated as much attention (Giampietro and Mayumi, 2009). Numerous organizations are advancing the concept of bio-chemical and thermo-chemical processes that produce fuels like green gasoline, green diesel and green aviation fuel. Some 4th generation technology pathways include pyrolysis, gasification, upgrading, solar-to-fuel and genetic manipulation of organisms to secrete hydrocarbons (Awudu and Zhang, 2012).

Governments may consider any of the following courses of action to increase the pace of development: incentives, R&D, plant conversions, capital, new uses and demand for co-products and technology transfer to realize breakthroughs and to make next generation biofuels cost competitive. Policies that could help commercialize next generation biofuels are crucial and should be tailored to support the development of the most advantageous

ones. Policies that could help commercialize next generation biofuels are crucial and should be tailored to support the development of the most advantageous improvements for a given conversion pathway. Incentive schemes should take an integrated approach combining rural development, climate change, energy provision, compliance with international quality standards and sustainability criteria. One way to promote rapid development will be to partner with the private sector as seen with the technological breakthroughs that have led to dramatic cost reductions (thirty-fold decrease) (WWI, 2007) in the enzymes needed for the breakdown of cellulose (enzymatic hydrolysis). Research leading to more valuable co-products also has the potential of lowering the overall cost of next generation biofuels.

Feedstock production is another area for potential cost reduction; increased crop productivity can lead to (1) lower overall production costs (2) improvement in the 'fossil' energy balance and (3) a reduction in the negative environmental impact of the biofuel. This could probably be realized in the short-to-medium-term through the genetic modification of energy crops leading to higher yields. For 2^{nd} generation biofuels the premise is that they would be less intensive in their demand for agricultural land, have improved 'fossil' energy balances, lead to a significant reduction in greenhouse gas and place less demand on prime food crop lands (e.g., jatropha and switchgrass could be grown on impoverished soils, use of SRC, utilizing residues from farm, crop, agricultural and forestry activities and microalgae).

The development of renewable and sustainable lignocellulosic biofuels is currently receiving worldwide attention and investment. Despite decades of research, there remain significant challenges to be overcome before these biofuels can be produced in large volumes at competitive prices. One obstacle is the lack of efficient and affordable catalytic systems to dissolve and hydrolyze polysaccharides into sugars. These sugars are then fed to micro-organisms and fermented into biofuels. The price of these catalysts be they biological, thermochemical, or chemical in nature, represent one of the largest costs in the conversion process (Simmons, 2011).

6.3 Integrated Refining Concepts – The Biorefinery

As new bioprocesses come to commercialization, economic and technical hurdles need to be overcome before their full potential can be realized. The inherent characteristics and limitations of biomass feedstocks have focused the development of efficient methods of chemically transforming and upgrading biomass feedstocks in a biorefinery (the concept is similar to that of a

modern oil refinery). A biorefinery is a highly integrated complex that will efficiently separate biomass raw materials into individual components and convert these into marketable products (energy, fuel, chemicals) (Chapter 1, Section 1.7 The Biorefinery Concept) (Mandil and Shihab-Eldin, 2010).

The refinery would be based on two technology platforms depending on the slate of products required (1) sugar based (chemical and biological conversion) and (2) thermochemical conversion. The sugar-based platform involves the breakdown of biomass into raw component sugars using chemical and biological means. The raw fuels may then be upgraded to produce fuels and chemicals that are interchangeable with existing commodities such as transportation fuels, oils and hydrogen. Every element of the plant feedstock will be utilized including lignin and require the application of a wide variety of thermochemical and state-of-the-art bioprocesses. The production of biofuels in the biorefinery complex will service existing high volume markets, providing economy of scale benefits and large volumes of byproducts which can be upgraded to valuable chemicals. A key requirement will be the ability to develop processing technology that can economically access and convert the five-and six-membered ring sugars in cellulose and hemicellulose to a fermentable substrate.

Advancing the bio-refinery concept is expected to come from (1) animal and crop residues used as fuel feedstocks, process energy and co-products in modern facilities, such as in the United States corn kernels used to produce dried distillers grain (DDG, animal feed) and glycerin from biodiesel production used in cosmetics and soaps (2) maximizing the efficient use of water, energy and chemicals and recycling of wastewater and the reuse of waste heat *e.g.* in Brazil, bagasse (sugarcane stalks from which juice has been extracted) when burned provides all of the process energy required to make ethanol and in some cases distilleries generate and export electricity to the grid.

The waste from the distilleries could also be used in the production of biogas and fertilizer, reducing fossil fuel energy needs further (little or no manufactured fertilizer is required). The result is that Brazilian sugarcane ethanol performs much better in the fossil fuel energy balance than other biofuel production pathways. In addition, the ability of the bioconversion platform to isolate lignocellulose into its constituents (cellulose, hemicellulose and lignin) was initially limited but recent advances have made the process more commercially viable. Thus, there is now an added potential for value-added products that can utilize lignin as the starting feedstock. Improving the effectiveness of pretreatment processes, decreasing the cost of enzymatic hydrolysis, improving overall process economics and efficiencies and creating co-products will positively impact the revenue side of the equation and reduce the

production costs of plant based chemicals and facilitate their substitution into existing markets.

By producing multiple products a biorefinery can take advantage of the difference in biomass components and intermediaries and maximize the value from the biomass feedstock. Greenhouse gas production associated with lignocellulosic based feedstocks is anticipated to be much lower (Chapter 4, Section 4.2 Energy Balance and Energy Efficiency of Biofuels). As biorefining technology advances, emphasis will be placed on biofuels as a viable large scale and environmentally sustainable alternative (Speight, 2011a). A biorefinery may produce one or several low volume high value chemical products (enhance value and profitability) and a high-volume, low-value liquid transportation fuel (that meets national transportation needs) while generating electricity and process heat (reducing the cost and avoiding greenhouse gas emissions).

6.3.1 The Biorefinery Concept

Biorefining is not new if activities such as the production of vegetable oils, beer and wine requiring pretreatment are considered. Many of these activities are known to have been in practice for millennia.

Biorefining offers a method to accessing the integrated production of chemicals, materials and fuels. Although the concept of a biorefinery is analogous to that of an oil refinery, the differences in the various biomass feedstocks require a divergence in the methods used to convert the feedstocks to fuels and chemicals (Ruth, 2004; Speight, 2014). Thus, a biorefinery, like a petroleum refinery, may need to be a facility that integrates biomass conversion processes and equipment to produce fuels, power and chemicals from biomass (Speight, 2011a). Furthermore, a biorefinery would integrate a variety of conversion processes to produce multiple product streams such as motor fuels and other chemicals from biomass such as the inclusion of gasification processes and fermentation processes, to name only two possible processes options.

A key requirement for the biorefinery is the ability of the refinery to develop process technology that can economically access and convert the five-and six-membered ring sugars present in the cellulose and hemicellulose fractions of the lignocellulosic feedstock. Although engineering technology exists to effectively separate the sugar containing fractions from the lignocellulose, the enzyme technology to economically convert the five ring sugars to useful products requires further development.

As a feedstock, biomass can be converted by thermal or biological routes to a wide range of useful forms of energy including process heat, steam, electricity, as well as liquid fuels, chemicals and synthesis gas. As a raw material,

biomass (by the very broad definition) is a worldwide feedstock due to its versatility, domestic availability and renewable character. At the same time, it also has its limitations. For example, the energy density of biomass is low compared to that of coal, liquid petroleum, or petroleum-derived fuels. The heat content of biomass, on a dry basis (16,240 to 20,880 KJ/kg) is at best comparable with that of a low-rank coal or lignite and substantially (50 to 100%) lower than that of anthracite, most bituminous coals and petroleum (Speight, 2008, 2011a, 2013a). Most biomass, as received, has a high burden of physically adsorbed moisture, up to 50% by weight. Thus, without substantial drying, the energy content of a biomass feed per unit mass is even less.

If the biorefinery is truly analogous to an oil refinery in which crude oil is separated into a series of products, such as gasoline, heating oil, jet fuel and petrochemicals, the biorefinery can take advantage of the differences in biomass components and intermediates and maximize the value derived from the biomass feedstock. A biorefinery might, for example, produce one or several low-volume but high-value chemical products and a low-value but high-volume liquid transportation fuel, while generating electricity and process heat for its own use the sale of excess electricity and heat production. The high-value products enhance profitability, the high-volume fuel helps meet national energy needs and the power production reduces costs and avoids greenhouse-gas emissions.

6.3.2 Process Options

A petroleum refinery is a series of integrated unit processes by which petroleum can be converted to a slate of useful (salable) products. A petroleum refinery, as currently configured, is unsuitable for processing raw or even partially processed, biomass. A typical refinery might be suitable for processing products such as gaseous liquid or solid products from biomass processing. These products from biomass might be acceptable as a single feedstock to a specific unit or, more likely, as a feedstock to be blended with refinery streams and to be co-processed in various refinery units. Thus, a biorefinery, in the early stages of development, would most likely be a series of unit processes which covert biomass to a primary product that requires further processing to become the final saleable product.

Biomass conversion is accomplished through the use of several distinct processes which include both biochemical conversion and thermal conversion to produce gaseous, liquid and solid fuels which have high energy contents, are easily transportable and are therefore suitable for use as commercial fuels. The basic types of processes used to generate energy from biomass as might be incorporated into a biorefinery are: (1) direct

combustion, (2) gasification, (3) pyrolysis or thermal decomposition, (4) anaerobic digestion, (5) fermentation and (6) transesterification.

6.3.2.1 Direct Combustion

Direct combustion involves burning the energy crop (including wood, agricultural residues, wood pulping liquor, municipal solid waste and refuse-derived fuel) and then using the resulting hot combustion gases to raise steam. The steam is, in turn, used to drive a steam turbine which drives a generator to produce electricity. The conversion efficiency from energy crop to energy is fairly low, especially for small systems, but this is balanced by the relatively low capital cost of direct combustion systems and the fact that the technology is tried and tested. Furthermore, using the waste heat produces much better efficiencies and economics.

Fluidized-bed combustors burn biomass fuel in a hot bed of granular material, such as sand. Injection of the air into the bed creates turbulence resembling a boiling liquid. The turbulence distributes and suspends the fuel. This design increases heat transfer and allows for operating temperatures below 972°C (1700°F), reducing nitrogen oxide (NOx) emissions. Fluidized-bed combustors can handle high-ash fuels and agricultural biomass residue.

Conventional combustion equipment is not designed for burning agricultural residues. Straw and grass contain alkali (potassium and sodium) compounds, which are also present in all annual crops and crop residues and in the annual growth of trees and plants. During combustion, alkali combines with silica, which is also present in agricultural residues. This reaction causes slagging and fouling problems in conventional combustion equipment designed for burning wood at higher temperatures.

Co-firing biomass as a secondary fuel in a coal-burning power plant using high-sulfur coal could help reduce sulfur dioxide and nitrogen oxide emissions. Also, co-firing decreases net carbon dioxide emissions from the power plant (if the biomass fuel comes from a sustainable source). Co-firing may require wood fuel preparation or boiler modifications to maintain boiler efficiency.

6.3.2.2 Gasification

Gasification is a high temperature process, which produces gas that can then be used in an internal combustion engine or fuel cell.

Before biomass can be gasified it must be pre-treated to meet the processing constraints of the gasifier. This typically involves size reduction and drying to keep the moisture content below specific levels. Thereafter, biomass gasification involves heating biomass in the presence of low levels of

oxygen (i.e. less than required for complete combustion to carbon dioxide and water). Above certain temperatures the biomass will break down into a gas stream and a solid residue. The composition of the gas stream is influenced by the operating conditions for the gasifier. In particular, simple gasification with air creates a synthesis gas stream that is diluted with large quantities of nitrogen. This nitrogen is detrimental to subsequent methanol processing and so techniques using indirect gasification or an oxygen feed are preferred. For large-scale gasification, pressurized systems are considered to be more economic than atmospheric systems.

In the gasifier, biomass is converted into a gaseous mixture of hydrogen, carbon monoxide, carbon dioxide and other compounds by applying heat under pressure in the presence of steam and a controlled amount of oxygen. The biomass produces synthesis gas.

$$C_6H_{12}O_6 + O_2 + H_2O \rightarrow CO + CO_2 + H_2 + \text{other products}$$

The above reaction uses glucose as a surrogate for cellulose. Biomass has highly variable composition and complexity, with cellulose as one major component.

Gasification occurs through the thermal decomposition of biomass with the help of an oxidant such as pure oxygen or oxygen enriched air to yield a combustible gas such as synthesis gas (syngas) rich in carbon monoxide and hydrogen. The synthesis gas is post-treated, by steam reforming or partial oxidation, to convert the hydrocarbons produced by gasification into hydrogen and carbon monoxide. The carbon monoxide is then put through the shift process to obtain a higher fraction of hydrogen, by carbon dioxide-removal and methanation or by pressure swing adsorption (Mokhatab et al., 2006).

Environmental concerns include the disposal of associated tars and ashes, particularly for the fluidized bed reactors, where these substances must be separated from the flue gas stream (in contrast to the pyrolysis plants, where most tar and ash deposits at the bottom of the reactor). Concerns over biomass transportation are similar to those mentioned above for fermentation and a positive fertilizer effect can also, in many cases, be derived from the gasification residues.

Methods proposed for the production of fuels from biomass involve the conversion of the biomass to a suitable synthesis gas, after which processing steps are very similar to those developed for methanol from natural gas (Chadeesingh, 2011; Speight, 2013b). However, the gasification techniques proposed are still in a relatively early stage of development using biomass feed and the methods are based on similar techniques used widely already with natural gas as feed.

The simplest type of gasifier is the *fixed bed counter current gasifier*. The biomass is fed at the top of the reactor and moves downwards as a result of the conversion of the biomass and the removal of ashes. The air intake is at the bottom and the gas leaves at the top. The biomass moves counter current to the gas flow and passes through the drying zone, the distillation zone, reduction zone and the oxidation zone.

The major advantages of this type of gasifier are its simplicity, high charcoal burn-out and internal heat exchange leading to low gas exit temperatures and high gasification efficiency. In this way, biomass feedstocks with high moisture content (up to 50% w/w) can be used. Major drawbacks are the high amounts of tar and pyrolysis products, because the pyrolysis gas is not lead through the oxidation zone. This is of minor importance if the gas is used for direct heat applications in which the tar is burned.

In the conventional *downdraft gasifier* (sometime called the *co-flow* gasifier), biomass is fed at the top of the reactor and air intake is at the top or from the sides. The gas leaves at the bottom of the reactor, so the fuel and the gas move in the same direction. The pyrolysis gases are lead through the oxidation zone (with high temperatures) and or more or less burned or cracked. Therefore, the producer gas has low tar content and is suitable for engine applications. In practice however, a tar-free gas is seldom if ever achieved over the whole operating range of the equipment. Because of the lower level of organic components in the condensate, downdraft gasifiers suffer less from environmental objections than updraft gasifiers.

The successful operation of a downdraft gasifier requires drying the biomass fuel to a moisture content of less than 20 percent. The advantage of the downdraft design is the very low tar content of the producer gas. However, the disadvantages of the downdraft gasifier are (1) the high amounts of ash and dust particles in the gas, (2) the inability to operate on a number of unprocessed fuels, often pelletization or briquetting of the biomass is necessary, (3) the outlet gas has a high temperature leading to a lower gasification efficiency and (4) the moisture content of the biomass must be less than 25% by weight.

A more recent development is the *open core* gasifier design for the gasification of small-sized biomass with high mineral matter content (therefore a high ash producing propensity). In the open core gasifier the air is sucked over the whole cross section from the top of the bed. This facilitates better oxygen distribution since the oxygen will be consumed over the whole cross section, so that the solid bed temperature will not reach the local extremes (hot spots) observed in the oxidation zone of conventional gasifiers due to poor heat transfer. The gasification process is amenable to a variety of biomass feedstocks such as waste rice hulls, wood waste, grass

and the dedicated energy crops. Gasification is a clean process with few air emissions and, when crops are used as the feedstock, little or no ash.

6.3.2.3 Pyrolysis

Pyrolysis is a medium temperature method which produces gas, oil and char from crops which can then be further processed into useful fuels or feedstock (Boateng et al., 2007; Speight, 2011a).

Wood and many other similar types of biomass which contain lignin and cellulose, (agricultural wastes, cotton gin waste, wood wastes, peanut hulls etc.) can be converted through a thermochemical process, such as pyrolysis, into solid, liquid or gaseous fuels. Pyrolysis, used to produce charcoal since the dawn of civilization, is still the most common thermochemical conversion of biomass to commercial fuel.

During pyrolysis, biomass is heated in the absence of air and breaks down into a complex mixture of liquids, gases and a residual char. If wood is used as the feedstock, the residual char is what is commonly known as charcoal. With more modern technologies, pyrolysis can be carried out under a variety of conditions to ensure complete capture of all products. Direct hydrothermal liquefaction involves converting biomass to an oily liquid by contacting the biomass with water at elevated temperatures (300 to 350°C, 570 to 660°F) with sufficient pressure to maintain the water primarily in the liquid phase for residence times up to 30 minutes. Alkali may be added to promote organic conversion. The primary product is an organic liquid with reduced oxygen content (approximately 10%) and the primary byproduct is water containing soluble organic compounds.

6.3.3 Anaerobic Digestion

Anaerobic digestion is a natural process and is the microbiological conversion of organic matter to methane in the absence of oxygen. The *biochemical conversion* of biomass is completed through alcoholic fermentation to produce liquid fuels and anaerobic digestion or fermentation, resulting in biogas (hydrogen, carbon dioxide, ammonia and methane) usually through four steps (hydrolysis, acidogenesis, acetogenesis and methanogenesis).

Hydrolysis:

Carbohydrates → sugars
Fats → fatty acids
Proteins → amino acids

Acidogenesis:

Sugars → carbon acids + alcohols + hydrogen + carbon dioxide + ammonia
Fatty acids → carbon acids + alcohols + hydrogen + carbon dioxide + ammonia
Amino acids → carbon acids + alcohols + hydrogen + carbon dioxide + ammonia

Acetogenesis:

Carbon acids + alcohols → acetic acid + carbon dioxide + hydrogen

Methanogenesis:

Acetic acid → methane + carbon dioxide

The decomposition is caused by natural bacterial action in various stages and occurs in a variety of natural anaerobic environments including water sediment, waterlogged soils, natural hot springs, ocean thermal vents and the stomachs of various animals (e.g., cows). The digested organic matter resulting from the anaerobic digestion process is usually called *digestate*.

The process of anaerobic digestion occurs in a sequence of stages involving distinct types of bacteria. Hydrolytic and fermentative bacteria first break down the carbohydrates, proteins and fats present in biomass feedstock into fatty acids, alcohol, carbon dioxide, hydrogen, ammonia and sulfides. Next, acetogenic (acid-forming) bacteria further digest the products of hydrolysis into acetic acid, hydrogen and carbon dioxide. Methanogenic (methane-forming) bacteria then convert these products into biogas.

The biogas produced in a digester (*digester gas*) is actually a mixture of gases, with methane and carbon dioxide making up more than 90 percent of the total. Biogas typically contains smaller amounts of hydrogen sulfide, nitrogen, hydrogen, methyl mercaptans and oxygen.

6.3.4 Fermentation and Hydrolysis

A number of processes allow biomass to be transformed into gaseous fuels such as methane or hydrogen (Sørensen et al., 2006). One pathway uses algae and bacteria that have been genetically modified to produce hydrogen directly instead of the conventional biological energy carriers. A second pathway uses plant material such as agricultural residues in a fermentation process leading to biogas from which the desired fuels can be isolated. This technology is established and is in widespread use for waste treatment, but often with the energy produced only for onsite use, which

often implies less than maximum energy yields. Finally, high-temperature gasification supplies a crude gas, which may be transformed into hydrogen by a second reaction step. In addition to biogas, there is also the possibility of using the solid by-product as a biofuel.

Traditional fermentation plants producing biogas are in routine use, ranging from farms to large municipal plants. As feedstock they use manure, agricultural residues, urban sewage and waste from households and the output gas is typically 64% methane. The biomass conversion process is accomplished by a large number of different agents, from the microbes decomposing and hydrolyzing plant material, over the acidophilic bacteria dissolving the biomass in an aquatic solution and to the strictly anaerobic methane bacteria responsible for the gas formation. Operating a biogas plant for a period of some months usually makes the bacterial composition stabilize in a way suitable for obtaining high conversion efficiency (typically above 60%, the theoretical limit being near 100%) and it is found important not to vary the feedstock compositions abruptly if optimal operation is to be maintained. Operating temperatures for the bacterial processes are only slightly above ambient temperatures, e.g. in the mesophilic region it is only around 30°C.

6.3.5 Transesterification

The transesterification process is a means of biodiesel production (Marchetti et al., 2005) in which glycerin is separated from the fat or vegetable oil (Schuchardta et al., 1998.). The process leaves behind two products: (1) methyl esters (the chemical name for biodiesel) and (2) glycerin (a valuable byproduct usually sold to be used in soaps and other products).

$$\text{Triglycerides} + \text{Monohydric alcohol} \leftrightarrow \text{Glycerin} + \text{Mono-alkyl esters}$$

Biodiesel (fatty acid methyl esters; FAME) is a notable alternative to the widely used petroleum derived diesel fuel since it can be generated by domestic natural sources such as soybeans, rapeseeds, coconuts and even recycled cooking oil, thus reducing dependence on diminishing petroleum fuel from foreign sources. In addition, because biodiesel is largely made from vegetable oils, it reduces lifecycle greenhouse gas emissions by as much as 78% (Ban-Weiss et al., 2007).

A variety of oils can be used to produce biodiesel. Virgin oil feedstock, rapeseed and soybean oils are most commonly used and soybean oil alone accounts for about ninety percent of all fuel stocks. It also can be obtained from field pennycress and Jatropha as well as other crops such as mustard, flax, sunflower, canola, palm oil and hemp.

Catalysts used for the transesterification of triglycerides are classified as alkali, acid, enzyme. Alkali-catalyzed transesterification is much faster than acid-catalyzed transesterification and is most often used commercially (Ma and Hanna, 1999). Quite often, for the base-catalyzed transesterification, the best yields were obtained when the catalyst was used in a small concentration, i.e. 0.5% wt/wt of oil (Stavarache et al., 2005). On the other hand, the data shows that during the production of free and bound ethyl ester (FAEE) from castor oil, hydrochloric acid is much more effective than sodium hydroxide at higher reaction temperatures (Meneghetti et al., 2006).

6.4 Strategies for Biofuel Use

Biodiesel can be used only in diesel engines. Even if there are examples of manufacturers of light duty vehicles who accept biodiesel in some of their models, biodiesel today is primarily used in buses and heavy-duty vehicles (trucks and buses). When a manufacturer accepts the use of a fuel, it is with a full warranty. In the instruction manual for the vehicle it should be clearly expressed what fuel or fuels can be used in the vehicle with the full warranty. If there is any doubt about this issue, the authorized car dealer can be contacted for further information about the specific case. In some cases manufacturers of heavy-duty trucks are prepared to accept higher blends of biodiesel in their engines with full warranties, but first after a relevant contract (such as for servicing requirements) has been signed between the manufacturer and the owner of the truck.

However, the biodiesel has to meet the relevant specifications (ASTM D975; ASTM D7462; ASTM D7467) and the range of the service intervals has to be decreased compared to when the vehicle is fueled by diesel oil. These types of contracts are also in most cases restricted to fleet owners and normally no such contracts are available for private persons and small fleet owners with just one or a few trucks.

The use of and more advanced exhaust gas treatment technology (such as use of regenerating particulate filters) has caused some manufacturers to re-examine the production and use of biodiesel. When regenerating the filters, the exhaust gas temperature is increased by late injection of the fuel in the cylinder. As biodiesel has a higher boiling point than diesel oil, a consequence might be that biodiesel is mixed with the engine oil. This dilution can be dealt with when using up to 5 % or even maybe 7 % biodiesel in the diesel oil, but with higher blends the impact of the use of biodiesel might be more severe (Dwivedi et al., 2011; Xue et al., 2011).

Another problem that might occur when using neat biodiesel or higher blends of biodiesel and diesel oil is the increased emission of NOx compared to neat fossil diesel oil. On the other hand, a higher blending of biodiesel in diesel oil will decrease particulates in the exhaust gas. Furthermore, the engine has to be adapted to biodiesel when it comes to sealing, gaskets and rubber hoses; otherwise these parts will be affected after a while and will start to decompose resulting in leakage.

Advancements in flexible fuel vehicle (FFV) technology are expected to be driven by the following:

- Improved engine design that takes advantage of the properties of biofuels (higher oxygen content, higher octane *etc*.).
- New and revised fuel specifications and standards that lead to improved engine performance.
- Fine-tuning engine control systems to run on varying blends (max fuel efficiency, min emissions across a wide range of blends). For example, high biodiesel blends can reduce health risks and improve air quality due to a reduction in particulates.
- Materials (tubes, hoses, connectors *etc*. minimize emissions to the environment).
- Additives that help reduce NOx and harmful emissions from blends of fossil and biofuels. High blend fuels in properly optimized vehicles can reduce public health risks especially from particulates.

To support flex-fuel vehicle initiatives, distribution infrastructure will need to be developed. Governments will require oil companies to provide biofuels at service stations (on a phased basis as biofuels become more accessible). Small refueling stations must also be included since they have a higher chance of success and a greater flexibility. International fuel quality standards will need to be agreed upon and enforced to provide consumer confidence and automakers with the assurance of consistent fuel characteristics so they can honor vehicle warranties. Emission standards will also need to be developed for the transport and combustion of biofuels.

6.5 Market Barriers of Biofuel

The promotion of renewable energies is faced by various market barriers. These barriers limit the development of renewables unless special policy

measures are enacted, unless no other fossil resources are available or the price advantage of renewables highly exceeds that of fossil fuels. In order to promote a fast introduction of biofuels, barriers have to be detected and solutions have to be found.

In general, the four main categories of barriers to the use of renewable energy technologies are (1) commercialization barriers faced by new technologies competing with mature technologies, (2) price distortions from existing subsidies and unequal tax burdens between renewables and other energy sources, (3) the failure of the market to value the public benefits of renewables and (4) other market barriers such as inadequate information, lack of access to capital and high transaction costs.

Economic barriers include the production of biofuels, which is still expensive, immature markets and beneficial externalities are not considered. Technical barriers include the quality of the fuel, which in many cases is not constant and conversion technologies for certain biofuels are still underdeveloped (e.g. for synthetic biofuels). Trade barriers such as the lack of quality standards for certain biofuels exist. Infrastructure barriers, which depend on the type of biofuel, indicate that new or modified infrastructure is needed. This is especially true for the use of bio-hydrogen and bio-methane, which need profound infrastructural changes.

In addition, before the owners of filling stations sell biofuels, automobile manufacturers may need to produce refitted vehicles. On the other hand, the automotive industry claims that the infrastructure has to be developed first. This dilemma is a visible barrier for the introduction of flex-fuel vehicles and the promotion of E85 in some European countries.

Well-established markets such as the US and the EU have enormous fuel needs and growing energy security concerns. These countries are large enough to accommodate both the domestic production and imports and the growth of the market hinges to some extent on how quickly the infrastructure is built. International trade is expected to ease fuel supply needs, linking a large number of producers in order to minimize the risk of supply disruption. However, industrialized countries employ tariffs and subsidies to support their own biofuel producers and keep commodities from other countries out of their markets. The US, EU and Australia, large agricultural exporting economies, have imposed import duties and other restrictions on foreign ethanol and biodiesel (Chapter 3 Biofuel Policies, Section 3.5 International Trade).

Agricultural subsidies in the developed countries have been blamed for supporting food production that harms competitors in developing countries. In the EU, part of this subsidy has now been shifted to biofuel production and the US is contemplating doing the same. While this appears to be a

step in the right direction, what is developing is a shift from highly protected and subsidized food production to highly subsidized and protected biofuel production, which should not be the aim. Developing countries must lobby the industrialized ones for reductions and eventual dismantling of tariffs, subsidies and import duties to give their nascent biofuel programs a chance to take root and compete for market share in the developed markets.

There are increasing calls for the biofuel trade to be certified to social and environmental standards to provide a means to ensure its production provides positive impacts. If certification schemes are not developed in a participatory and transparent manner with developing and emerging countries they could be viewed as further barriers by industrialized countries to protect their domestic producers. In addition, the biofuel trade needs to be based on sound standards and promote sustainability; a balance must be struck between developing complicated certification schemes and putting safeguards in place to direct the market (Chapter 3). Gradual development for such schemes is probably the best approach allowing for gradual learning and expansion; existing schemes could provide useful information.

Any proposed scheme should be thorough, comprehensive, transparent, reliable and cost effective; it should not create hurdles for the industry. Industrialized countries could provide technical assistance, incentives and financing for developing and emerging countries and help to ensure that standards address the issue of 'leakage' effects. Additional research is required into the setting up of an independent international certification body; this should be done in collaboration with all stakeholders (and would help to ensure the sustainability and feasibility of the biomass trade).

6.6 Managing Biofuel Production

In economic terms, first-generation biofuels such as bioethanol and biodiesel give rise to divergent opinions across countries. In Brazil, bioethanol production costs have declined after sustained efforts by the government since the mid-1970s, with research and development, an integrated institutional approach and yield enhancement. The same claim cannot be made of the biofuels program in other parts of the world. Bioethanol programs to accelerate the reduction of carbon emissions also have a long way to go in other developing countries of South Asia, including Sri Lanka and Bangladesh. Within several countries – the European Union (EU), the United States as well as India and parts of Africa, biofuel production costs are variable and not always on a downward trend, partly because of the feedstock variety required to generate an adequate biofuel supply. This

economic picture will need to be resolved and stabilized as biofuel production moves into the latter part of this century and beyond.

In addition, there are three major areas that need consideration in the future for the production of biofuels: (1) resolving the food or fuel issues, (2) the use of non-food feedstocks and (3) the use of vegetable oil.

6.6.1 Food or Fuel

The *food or fuel* debate will continue to be the dilemma facing the production of crops and the use of crop land for the production of biofuels. The risk of diverting farmland or crops for biofuels production in detriment to the food supply on a global scale will remain a major hurdle for biofuel production. The debate is international in scope and there is disagreement about how significant the issue is, what is causing it and what can or should be done to resolve the issues. Biofuel production has increased in recent years. Some commodities such as maize (corn), sugarcane or vegetable oil can be used either as food or feedstock to produce biofuels.

However, biofuel feedstocks can have both direct and indirect effects on food supplies. If biofuels are produced from feedstocks that would have been used for food, then biofuels directly reduce potential food supplies. This reduction occurs even if feedstock prices increase and result in an expansion of supply because the expanded feedstock supply will typically reduce the supply of other food crops. For example, US corn used to produce ethanol reduces the amount of feed available for livestock. The large expansion in the supply of corn in response to ethanol's growth reduces the amount of acres planted for soybeans in the United States. In aggregate, there are fewer acres devoted to food production than there would be in the absence of biofuels.

Even if a feedstock is not directly used to produce biofuels, it can still affect food supplies if the feedstock is grown on land that would otherwise be planted with a food crop. For example, oil from jatropha is not suitable for human consumption. However, if jatropha plantations are sited on prime agricultural land, then biodiesel produced from jatropha will decrease food supplies. If the plantations are located on land that is not suitable for food crop production, then the effects are minimal, perhaps limited to a reduction in some grazing land. Similarly, if dedicated biomass crops such as switchgrass or miscanthus are planted on agricultural ground, then food supplies will be affected.

It would seem that because biofuels require biomass and because biomass typically requires land, there will always be a connection between biofuel production and food supplies. But a lot of biomass is produced that has little, if any, impact on the amount of land available to produce food.

Tapping these sources of biomass for future increases in biofuel production would help to break the link between food and energy prices and would significantly increase the net reduction in greenhouse gas emissions that we can obtain from biofuels.

6.6.2 Non-Food Feedstocks

Producing biofuels from feedstocks that cannot be used directly for food production or do not reduce the amount of land that can be used to produce food can be accomplished in two ways. The most straightforward way is to capture biomass that is currently treated as either waste or that is a co-product of existing production processes with very low or negative current economic value. Examples of waste streams that potentially could be converted into biofuels include a portion of municipal trash and garbage, crop residues, wood pulp residues and forest residues.

Crop residue, in particular corn stover, has been identified as a waste stream that could be tapped for conversion into cellulosic biofuels. Not all stover, however, is a waste product. On highly erodible land, corn stover is an efficient means of reducing soil erosion. In addition, some fraction of stover likely contributes to the maintenance of soil organic content, which helps to maintain soil fertility. However, many farms in the Corn Belt of the United States treat a large proportion of corn stover as a waste product needing to be managed. Excess stover in fields can prevent the timely planting of the following year's crop, particularly if corn is planted after corn.

The by-products of vegetable oil refining represent another potential waste stream. Nearly all biodiesel is produced from refined vegetable oils. The portion of the vegetable oil that is used for biodiesel is the triglyceride portion, which is the same portion used in food and food preparation. But biodiesel can also be produced from the by-products of edible oil production. Biodiesel made from soybean soap stock – a by-product of soybean oil processing that is high in free fatty acid content—is a high-quality fuel. Palm fatty acid distillate is a similar material that is in abundant supply given the large growth in palm oil production. The extent to which existing biodiesel plants can use these by-products may be limited but there are second-generation biodiesel plants that are in development that can operate completely on these feedstocks. Diversion of these materials from their current use (or from landfills) will likely add value to them and create highly valuable biofuels without increasing food prices. In addition, because using these feedstocks will not decrease cropland, their contributions to greenhouse gas reductions will likely be far greater than those of feedstocks that displace cropland.

The second way that biomass can be created without competing for food land is to use land that is not suitable for producing food or to grow the biomass without using land. Jatropha is an oil-bearing crop that its backers claim is suitable for growing in arid regions that would not otherwise be used for intensive agriculture. If this claim is borne out and jatropha is planted on this type of land only, then biodiesel made from jatropha will not compete with food.

Another example of biomass being produced on non-agricultural land is the planting of dedicated biomass crops on land that otherwise would not produce food. There are large areas in the upper Midwest United States and the Southeast United States that once produced food crops but have now been given over to pasture or trees. Conversion of these lands to the production of woody biomass to be used for cellulosic biofuels would not affect food prices.

A last example would be to produce biomass without extensive use of land by producing algae in ponds.

6.6.3 Vegetable Oil

Recent publications in the energy sector have highlighted the promise of hydrotreated vegetable oils (HVO), which are produced when hydrogen is used to remove the oxygen from the triglyceride or vegetable oil (Aatola, et al., 2009). This can be done utilizing any conventional hydrotreatment catalysts that are well known in industry (Knothe, 2010). As hydrotreated vegetable oil can be produced from any oil, non-edible oils can be used in large enough volumes to replace a significant portion of fossil-based diesel (Aatola, et al., 2009). Compared to biodiesel, hydrotreated vegetable oil has higher LHV (44MJ/kg vs 37–38MJ/kg) and cetane numbers (70 to 90 vs 50–65) and could possibly be integrated into typical petrochemical production streams (Aatola, et al., 2009; Knothe, 2010; Sunde, et al., 2011). However, as hydrotreated vegetable oil is so similar to conventional diesel, it does not have all of the environmental advantages reported for biodiesel as reduction in particulate matter and carbon monoxide emissions (Knothe, 2010). The first commercial plant form hydrotreating vegetable oil was built in Finland and several more are in the planning stages (Aatola, et al., 2009).

6.7 The Future

The impact of biofuels on the economies and environment of various countries will depend on the biofuel crop and the previous land use. Biofuels

can be beneficial to biodiversity when appropriate crops are grown in suitable areas. Furthermore, if the production and use of biofuels are conclusively shown to contribute to climate change mitigation, they have the potential to be indirectly beneficial to biodiversity as a whole (Campbell and Doswald, 2009).

However, biofuels have already been claimed to have a negative impact on biodiversity when direct conversion of natural ecosystems or indirect land conversion of non-degraded land occurs. The expansion of biofuel production in the tropics can result in the loss of tropical forests and wetlands and in temperate regions biofuel production has encroached onto set-aside lands. Biofuel feedstock plantations (particularly oil palm and maize plantations), have been shown to support far lower levels of biodiversity than natural ecosystems and can cause soil erosion and the pollution of watercourses.

While most analyses continue to indicate that 1st-generation biofuels show a net benefit in terms of greenhouse gas emissions reduction and energy balance, they also have several drawbacks. Current concerns for many, but not all, of the 1st-generation biofuels are that they do the following: (1) contribute to higher food prices due to competition with food crops, (2) are an expensive option for energy security taking into account total production costs excluding government grants and subsidies, (3) provide only limited reduction in greenhouse gas emissions, avoided, (4) do not meet their claimed environmental benefits because the biomass feedstock may not always be produced sustainably, (5) are accelerating deforestation, (6) potentially have a negative impact on biodiversity and (6) compete for scarce water resources in some regions (Sims et al., 2008).

Additional uncertainty has also recently been raised about the potential greenhouse gas emissions if indirect land use change is taken into account. The certification of biofuels and their feedstocks is being examined and could help to ensure biofuels production meets sustainability criteria, although some uncertainty over indirect land-use impacts is likely to remain. Additional concerns over the impact of biofuels on biodiversity and scarce water resources in some countries also need further un-biased evaluation.

Selected 1st-generation biofuels have contributed to the recent increases in world prices for food and animal feeds. However, much uncertainty exists in this regard and estimates of the biofuels contribution in the literature range from 15 to 25% of the total price increase (with a few at virtually zero or up to 75%). Regardless of the culpability, competition with food crops will remain an issue so long as 1st-generation biofuels produced from food crops dominate total biofuel production.

Production and the use of some biofuels can be an expensive option for reducing greenhouse gas emissions and improving energy security. Estimates for greenhouse gas mitigation from biodiesel and corn ethanol vary depending on the country and pathway. Given the relatively limited scope for cost reductions and growing global demand for food, little improvement in these mitigation costs can be expected in the short term.

Many of the problems associated with 1st generation biofuels can be addressed by the production of biofuels manufactured from agricultural and forest residues and from non-food crop feedstocks. Where the ligno-cellulosic feedstock is to be produced from specialist energy crops grown on arable land, several concerns remain over competing land use, although energy yields are likely to be higher than if crops grown for 1st generation biofuels (and co-products) are produced on the same land. In addition poorer quality land could possibly be utilized.

Depending to some extent on future oil prices, biofuels are likely to become a part of the solution to the challenge of shifting the transport sector towards more sustainable energy sources at some stage in the medium-term. However, major technical and economic hurdles are still to be faced before they can be widely deployed. Indeed, the use of biofuels is closely linked to available and future engine technologies. To replace conventional engine concepts which are based on mineral oil, two alternative strategies are principally pursued at the moment (short and long term strategy). These concepts differ mainly in the philosophy of the engines (Sims et al., 2008).

In the short term, the concept is based on further developments of today's combustion engine and the use of biofuels. Today this is the most promising approach. It is efficient and sustainable, as no additional infrastructure and no principally different engine technology is needed. The long-term approach favors a change to electric engines driven by fuel cells which work without producing emissions during vehicle use. However, numerous technical and economic challenges need to be overcome and today only few manufacturers produce hybrid vehicles (combinations of electric and combustion engines) already available on the market.

The common basic approach of these two concepts is that they will function in the long term only with renewable energy sources. The concepts also must be available at reasonable prices, contribute substantially to the reduction of CO_2 emission and exhibit a high potential as a substitute for conventional fuels. For the foreseeable future (at least until 2030) biofuels will mostly be used in internal combustion engines, as these technologies will still prevail.

Currently, there is no clear commercial or technical advantage between the biochemical pathway (which typically produces ethanol) and thermo-chemical pathway (which typically produces hydrocarbons via the Fischer-Tropsch reaction) for the production of biofuels (Speight, 2008, 2011a). Both types of technologies are under continual development and evaluation and have significant technical and environmental barriers still to be overcome.

For the biochemical route, much remains to be done in terms of (1) improving feedstock characteristics, (2) reducing the costs by perfecting pretreatment, (3) improving the ability of the enzyme systems to produce the desired product, (4) lowering the production costs and (5) improving overall process integration. The potential advantage of the biochemical route is that cost reductions have proved reasonably successful to date, so it could possibly provide cheaper biofuels than via the thermo-chemical route.

However, as a broad generalization, there are less technical hurdles to the thermo-chemical route since much of the technology is already recognized. One issue of concern is the ability of the industry to secure a sufficient enough quantity of feedstock for a reasonable delivered cost at the plant gate in order to meet the commercial-scale required to bring the process to favorable economics. Also perfecting the gasification of biomass (Speight, 2008, 2011a) at a reasonable cost is still under investigation, although good progress is being made.

One key difference between the biochemical and thermo-chemical routes of biofuel production is that the lignin component is a residue of the enzymatic hydrolysis process and can be used for heat and power generation. In the biomass-to-liquids process (BTL process) the feedstock is converted into synthesis gas along with the cellulose and hemicellulose biomass components (Speight, 2008; Chadeesingh, 2011; Speight, 2011a). The efficiency of both processes may be optimistically on the order of 35%, which, although relatively low, the overall efficiency of the process could be improved if surplus heat, power and co-product generation are included in the total system. Improving efficiency is vital to the extent that it reduces the final product cost and improves environmental performance, but it should not be a goal in itself. And there is always the inconsistency of the composition of the feedstock – although both routes have similar potential yields in energy terms, different yields occur in practice.

In short, major variations between the various processes under development, together with variations between biofuel yields from different feedstocks, add various degrees of complexity and several unknowns to the process efficiency and economics. The full production costs of biofuels

associated with both the biochemical and thermochemical pathways remain uncertain and comparison between the two process options has been sources of contention within the budding biofuels industry (Sims et al., 2008).

The main reasons for the major discrepancies between various published cost predictions relate to varying assumptions for feedstock costs and future timing of the commercial availability of both the feedstock supply chain and conversion technologies. Given that 2nd-generation biofuels are still at the pre-commercial stage, widespread deployment is expected to lead to the improvement of technologies, reduced costs from plant construction and operational experience. The potential for cost reductions is likely to be greater for ethanol produced via the biochemical route than for liquid fuels produced by the thermochemical route, because much of the technology for biomass-to-liquids plants (based on Fischer-Tropsch conversion) is mature and the process mainly involves linking several proven components together (Speight, 2008, 2011a) but there is scope for further cost reductions as the technology evolves.

As the demand for biofuels increases in the future so will the land requirements, which are likely to be detrimental to biodiversity (Campbell and Doswald, 2009). Furthermore post-conversion management can also negatively impact biodiversity through the pollution of fertilizers, for example. Some observers maintain that the *next generation* of biofuels will require less land or be more productive and therefore reduce negative biodiversity impacts though there is much uncertainty surrounding on this issue. The introduction of sustainability standards is one option to reduce the biodiversity impacts of biofuel production. However, the development and implementation of these standards may continue to be difficult, largely due to the lack of accepted definitions for key terms such as *high biodiversity* and *degraded lands*. In any case, it is likely that sustainability standards will only be part of the solution and will need to be combined with improved land use planning.

Finally, the key to the successful management and environmental administration of biofuel production and use lies in various policies and the choices of which policy to follow. There are many objectives that can be achieved through biofuel policies including three key policies (1) energy security, (2) diversification of the fuel base and (3) greenhouse gas reduction.

By any measure, the incentives given to corn ethanol and biodiesel have been successful at increasing the proportion of the fuel supply in the United States that comes from US-produced biofuels. However, one near-term cost of achieving this goal is higher corn and vegetable oil prices, which have increased and will continue to increase food prices. For many

consumers in the United States such a trade-off may make sense but for the poor nations of the world where food production is a premium, there is no trade-off, only loss – the poor use relatively little fuel and must pay higher prices for some food items. Another problem with diverting food crops for biofuels is that promised greenhouse gas reductions likely will not materialize because new cropland will be brought into production in response to higher commodity prices.

Typically, current biofuel policies do not clearly differentiate between biofuel productions that use feedstocks that affect food prices and the production of those biofuels those that do not use food crops. If the Congress of the United States and governments of other countries desire to place greater importance on minimizing the impact of biofuel development on food prices, the necessary steps should be defined and put into place immediately.

This will also require an increase in research programs related to biofuel production from *acceptable feedstocks*, with priority being given to developing feedstocks that do not affect food prices and that have large greenhouse gas reductions. The justification for this expanded research is that food, energy and climate change will likely be the three biggest issues facing the United States and the world over the next 10 to 20 years and the competent management of biofuel production is not only required but is very necessary.

References

Aatola, H., Larmi, M. and Sarjovaara, T. 2009. *Hydrotreated Vegetable Oil (HVO) as a Renewable Diesel Fuel: Trade-Off between NOx, Particulate Emission and Fuel Consumption of a Heavy Duty Engine.* SAE International Journal of Engines, 1: 1251–1262.

ARRA. 2009. American Recovery and Reinvestment Act. Congress of the United States, Washington, DC.

ASTM D975. *Standard Specification for Diesel Fuel Oils*. Annual Book of Standards. American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM D7462. *Standard Test Method for Oxidation Stability of Biodiesel (B100) and Blends of Biodiesel with Middle Distillate Petroleum Fuel (Accelerated Method).* Annual Book of Standards. American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM D7467. *Standard Specification for Diesel Fuel Oil, Biodiesel Blend (B6 to B20).* Annual Book of Standards. American Society for Testing and Materials, West Conshohocken, Pennsylvania.

Awudu, I and Zhang, J. 2012. *Uncertainties and Sustainability Concepts in Biofuel Supply Chain Management: A Review.* Renewable and Sustainable Energy Reviews 16: 1359– 1368.

Ban-Weiss, G.A., J.Y. Chen, B.A. Buchholz and R.W. Dibble. 2007. *A Numerical Investigation into the Anomalous Slight NOx Increase When Burning Biodiesel - A New (Old) Theory*. Fuel Processing Technology 88:659–667.

Boateng, A.A., Daugaard, D.E., Goldberg, N.M. and Hicks, K.B. 2007. *Ind. Eng. Chem. Res*. 46: 1891–1897.

Campbell, A. and Doswald, N. 2009. "The Impacts of Biofuel Production on Biodiversity: A Review of the Current Literature." United Nations Environmental Program-World Conservation Monitoring Center (UNEP-WCMC), Cambridge United Kingdom.

Carriquiry, A.M., Du, X. and Timilsina, R.G. 2011. *Second Generation Biofuels: Economics and Policies.* Energy Policy, 39: 4222–4234.

Chadeesingh, R. 2011. The Fischer Tropsch Process. *The Biofuels Handbook*. J.G. Speight (Editor). Royal Society of Chemistry, London, United Kingdom. Part 3, Chapter 5.

Chisti, Y. 2008. Biodiesel from Microalgae Beats Bioethanol. *Trends in Biotechnology*, 26: 126–131.

Coyle, W.T. 2010. "Next-Generation Biofuels: Near-Term Challenges and Implications for Agriculture." Report No. BIO-01–01. United States Department of Agriculutre, Washington DC.

Dwivedi, G., Jain, S. and Sharma, M.P. 2011. *Impact Analysis of Biodiesel on Engine Performance – A Review.* Renewable and Sustainable Energy Reviews, 15: 4633–4641.

Farrell, A.E., Plevin, R.J., Turner, B.T., Jones, A.D., O'Hare, M. and Kammen, D.M. 2006. Ethanol Can Contribute to Energy end Environmental Goals. *Science*, 311: 506–508.

Giampietro, M. and Mayumi, K. 2009. *The Biofuel Delusion – The Fallacy of Large-Scale Agro-fuel Production*. Earthscan, London, united Kingdom.

Gronenberg, L.S., Marccheschi, R.J. and Liao, J.C. 2013. *Next Generation Biofuel Engineering in Prokaryotes.* Current Opinion in Chemical Biology, 17(3): 462–471.

Hamelinck, C.N. and Faaij, A.P.C. 2006. *Outlook for Advanced Biofuels*. Energy Policy, 34(17): 3268–3283.

Herro, A. 2008. Better Than Corn? Algae Set to Beat Out Other Biofuel Feedstocks. *World Watch*, 21: 4.

Hill, J., Nelson, E., Tilman, D., Polasky, S. and Tiffany, D. 2006. "Environmental, Economic and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels." *Proceedings. National Academy of Sciences of the United States of America*, 103: 11206–11210.

Jenner, M. 2008. Algae - The Wonder Crop of Tomorrow? *BioCycle*, 49: 44.

Knothe, G. 2010. *Biodiesel and Renewable Diesel: A Comparison. Progress in Energy and Combustion Science*, 36: 364–373.

Ma, F. and Hanna, M.A. 1999. *Biodiesel production: a review.* Bioresource Technology 70:1–15.

Mandil, C. and Shihab-Eldin, A. 2010. "Assessment of Biofuels Potential and Limitations." International Energy Forum, Riyadh, Saudi Arabia. February.

Marchetti, J.M., Miguel, V.U. and Errazu, A.F. 2005. *Possible methods for biodiesel production.* Renewable and Sustainable Energy Rev. 11:1300–1311.

Meneghetti, P.S.M., Meneghetti, M.R., Wolf, C.R., Silva, E.C., Lima, G.E.S., Coimbra, D.A., Soletti, J.I. and Carvalho, S.H.V. 2006. *Ethanolysis of Castor and Cottonseed Oil: A Systematic Study Using Classical Catalysts.* JAOCS 83:819–822.

Mokhatab, S., Poe, W.A. and Speight, J.G. 2006. *Handbook of Natural Gas Transmission and Processing.* Elsevier, Amsterdam, Netherlands.

Patil, V., Tran, K.Q. and Giselrod, H.R. 2008. Towards Sustainable Production of Biofuels from Microalgae. *International Journal of Molecular Sciences*, 9: 1188–1195.

Robertson, G.P., Dale, V.H., Doering, O.C., Hamburg, S.P., Melillo, J.M., Wander, M.M., Parton, W.J., Adler, P.R., Barney, J.N., Cruse, R.M., Duke, C.S., Fearnside, P.M., Follett, R.F., Gibbs, H.K., Goldemberg, J., Mladenoff, D.J., Ojima, D., Palmer, M.W., Sharpley, A., Wallace, L., Weathers, K.C., Wiens, J.A. and Wilhelm, W.W. 2008. Agriculture – Sustainable Biofuels Redux. *Science*, 322: 49–50.

Ruth, M. 2004. "Development of a Biorefinery Optimization Model." Renewable Energy Modeling Series Forecasting the Growth of Wind and Biomass. National Bioenergy Centre, National Renewable Energy Laboratory, Golden, Colorado.

Schuchardta, U., Serchelia, R. and Vargas, R.M. 1998. *Transesterification of Vegetable Oils: a Review.* J. Braz. Chem. Soc. 9:199–210.

Simmons, B.A. (Editor). 2011. "Chemical and Biochemical Catalysis for Next Generation Biofuels." Royal Society of Chemistry, London, United Kingdom.

Sims, R., Taylor, M. and Saddler, J. 2008. "From 1st- 2nd Generation Biofuel Technologies: An Overview of Current RD&D Activities." OECD/IEA. International Energy Agency, Paris, France.

Sørensen, B.E., Njakou, S. and Blumberga, D. 2006. "Gaseous Fuels Biomass. Proceedings." World Renewable Energy Congress IX. WREN, London.

Speight, J.G. 2008. *Synthetic Fuels Handbook: Properties, Processes and Performance.* McGraw-Hill, New York.

Speight, J.G. (Editor). 2011a. *The Biofuels Handbook.* Royal Society of Chemistry, London, United Kingdom.

Speight, J.G. 2011b. *The Refinery of the Future.* Gulf Professional Publishing, Elsevier, Oxford, United Kingdom.

Speight, J.G. 2013a. *The Chemistry and Technology of Coal 3rd Edition.* CRC Press, Taylor & Francis Group, Boca Raton, Florida.

Speight, J.G. 2013b. *Coal-Fired Power Generation Handbook.* Scrivener Publishing, Salem, Massachusetts, 2013.

Speight, J.G. 2014. *The Chemistry and Technology of Petroleum.* 5^{th} Edition. CRC Press, Taylor and Francis Group, Boca Raton, Florida.

Stavarache, C., Vinatoru, M. Nishimura, R. and Maed, Y. 2005. *Fatty acids methyl esters from vegetable oil by means of ultrasonic energy*. Ultrasonics Sonochemistry 12:367–372.

Sunde, K., Brekk, A. and Birger, S. 2011. *Environmental Impacts and Costs of Hydrotreated Vegetable Oils, Trans-esterified Lipids and Woody BTL – A Review.* Energies, 4: 845–877.

Wang, B., Li, Y., Wu, N. and Lan, C.Q. 2008. CO2 Bio-Mitigation Using Microalgae. *Applied Microbiology and Biotechnology*, 79: 707–718.

Xue, J., Grift, T.E. and Hansen, A.C. 2011. *Effect of Biodiesel on Engine Performance and Emissions.* Renewable and Sustainable Energy Reviews, 15: 1098–116.

Conversion Factors

1. Weight

1 ounce (1 oz.) = 28.3495 grams (18.2495 g)
1 pound (1 lb) = 0.454 kilogram
1 pound (1 lb) = 454 grams (454 g)
1 kilogram (1 kg) = 2.20462 pounds (2.20462 lb)
1 stone (English, 1 st) = 14 pounds (14 lb)
1 ton (US; 1 short ton) = 2,000 lbs
1 ton (English; 1 long ton) = 2,240 lbs
1 metric ton = 2204.62262 pounds
1 tonne = 2204.62262 pounds

2. Temperature

$^{o}F = (^{o}C \times 1.8) + 32$
$^{o}C = (^{o}F - 32)/1.8$
$(^{o}F - 32) \times 0.555 = {}^{o}C$

3. Area

1 square centimeter (1 cm^2) = 0.1550 square inches
1 square meter 1 (m^2) = 1.1960 square yards
1 hectare = 2.4711 acres
1 square kilometer (1 km^2) = 0.3861 square miles
1 square inch (1 $inch^2$) = 6.4516 square centimeters
1 square foot (1 ft^2) = 0.0929 square meters
1 square yard (1 yd^2) = 0.8361 square meters
1 acre = 4046.9 square meters
1 square mile (1 mi^2) = 2.59 square kilometers

4. Other Approximations

14.7 pounds per square inch (14.7 psi) = 1 atmosphere (1 atm)
1 kiloPascal (kPa) × 9.8692 × 10^{-3} = 14.7 pounds per square inch (14.7 psi)
1 yd^3 = 27 ft^3
1 US gallon of water = 8.34 lbs
1 imperial gallon of water = 10 lbs
1 yd^3 = 0.765 m^3

Glossary

Abatement: Actions resulting in reductions to the degree or intensity of greenhouse gas emissions; also referred to as mitigation.

Acetic acid: An acid with the structure of CH_3COOH; acetyl groups are bound through an ester linkage to hemicellulose chains, especially xylans, in wood and other plants; the natural moisture present in plants hydrolyzes the acetyl groups to acetic acid, particularly at elevated temperatures.

Acid: Any of a class of substances whose aqueous solutions are characterized by a sour taste, the ability to turn blue litmus red, and the ability to react with bases and certain metals to form salts; a substance that yields hydrogen ions when dissolved in water and which can act as a proton (H^+) donor.

Acid detergent fiber (ADF): Organic matter that is not solubilized after 1 hour of refluxing in an acid detergent of cetyltrimethylammonium bromide in 1N sulfuric acid; includes cellulose and lignin; this analytical method is commonly used in the feed and fiber industries.

Acid hydrolysis: A chemical process in which acid is used to convert cellulose or starch to sugar.

Acid insoluble lignin: Lignin is mostly insoluble in mineral acids, and therefore can be analyzed gravimetrically after hydrolyzing the cellulose and hemicellulose fractions of the biomass with sulfuric acid; standard test method ASTM E1721 describes the standard method for determining acid insoluble lignin in biomass; see American Society for Testing and Materials.

Acid soluble lignin: A small fraction of the lignin in a biomass sample is solubilized during the hydrolysis process of the acid insoluble lignin method. This lignin fraction is referred to as acid soluble lignin and may be quantified by ultraviolet spectroscopy; see Lignin and Acid Insoluble Lignin.

Advanced biofuels: Biofuels manufactured from more sustainable feedstocks using advanced processing technology resulting in more efficient utilization of the feedstock and lower carbon dioxide emissions. One of the key benefits of advanced biofuels is that they will be manufactured from, for example, non-food crops such as ligno-cellulosic biomass. The use of lignocellulose

opens the way for biofuels to be manufactured from a much wider range of feedstocks in future, therefore increasing the overall supply potential for biofuels worldwide.

Advantaged molecule biofuels: The next generation biofuel products such as biobutanol. Compared to first generation biofuels, advantaged products offer better fuel characteristics with less need for vehicle modifications for use.

Adverse effects/impacts: The potential negative effects of human-induced climate change as well as the impacts resulting from implementation of response measures. Such effects or impacts include, e.g. sea level rise, changes in precipitation, storms or other weather patterns, and reduced demand for fossil fuels or other energy intensive products; the impacts of climate change can be positive as well as negative.

Aerosol: A dispersion of a liquid or solid in a gas.

Afforestation: The act or process of establishing a forest on land that has not been forested in the past 50 years.

Agitator: A device such as a stirrer that provides complete mixing and uniform dispersion of all components in a mixture; are generally used continuously during the thermal processes and intermittently during fermentation.

Agricultural residue: Agricultural crop residues are the plant parts, primarily stalks and leaves, not removed from the fields with the primary food or fiber product; examples include corn stover (stalks, leaves, husks, and cobs); wheat straw; and rice straw.

Air quality maintenance area: Specific populated area where air quality is a problem for one or more pollutants.

Alcohol: The family name of a group of organic chemical compounds composed of carbon, hydrogen, and oxygen. The molecules in the series vary in chain length and are composed of a hydrocarbon plus a hydroxyl group. Alcohol includes methanol and ethanol; a colorless volatile liquid created through the fermentation of sugars or starches.

Aldoses: Occur when the carbonyl group of a monosaccharide is an aldehyde.

Algae: Algae are primitive plants, usually aquatic, capable of synthesizing their own food by photosynthesis; currently being investigated as a possible feedstock for producing biodiesel.

Aliphatic: Any non-aromatic organic compound having an open chain structure.

Alkali: A soluble mineral salt.

Alkali lignin: Lignin obtained by acidification of an alkaline extract of wood.

Alkylation: a process for manufacturing high octane blending components used in unleaded petrol or gasoline.

Alternative energy: Energy derived from non-fossil fuel sources.

Alternative fuel:- As defined in the United States Energy Policy Act of 1992 (EPACT): methanol, denatured ethanol and other alcohols, separately or in blends of at least 10 percent by volume with gasoline or other fuels; compressed natural gas; liquefied natural gas, liquefied propane gas, hydrogen,

coal derived liquid fuels, fuels other than alcohols derived from biological materials, electricity, biodiesel, and any other fuel deemed to be substantially not petroleum and yielding potential energy security benefits and substantial environmental benefits.

Ambient air quality: The condition of the air in the surrounding environment.

American Society for Testing and Materials (ASTM): An international voluntary standards organization that develops and produces technical standards for materials, products, systems and services.

Anaerobic: Biological processes that occur in the absence of oxygen.

Anaerobic digestion: Decomposition of biological wastes by micro-organisms, usually under wet conditions, in the absence of air (oxygen), to produce a gas comprising mostly methane and carbon dioxide.

Anhydrous: without water; transesterification of biodiesel must be an anhydrous process; water in the vegetable oil causes either no reaction or cloudy biodiesel, and water in lye or methanol renders it less useful or even useless, depending on how much water is present.

Annual removals: The net volume of growing stock trees removed from the inventory during a specified year by harvesting, cultural operations such as timber stand improvement, or land clearing.

API gravity: a measure of the lightness or heaviness of petroleum that is related to density and specific gravity; $^{o}API = (141.5/sp\ gr\ @\ 60^{o}F) - 131.5$,

Aquatic plants: The wide variety of aquatic biomass resources, such as algae, giant kelp, other seaweed, and water hyacinth; certain microalgae can produce hydrogen and oxygen while others manufacture hydrocarbons and a host of other products; microalgae examples include Chlorella, Dunaliella, and Euglena.

Arabinan: The polymer of arabinose; can be hydrolyzed to arabinose.

Arabinose: A five-carbon sugar; a product of hydrolysis of arabinan found in the hemicellulose fraction of biomass.

Aromatics: a range of hydrocarbons which have a distinctive sweet smell and include benzene and toluene' occur naturally in petroleum and are also extracted as a petrochemical feedstock, as well as for use as solvents; examples include benzene, toluene, and xylene.

Atmospheric pressure: Pressure of the air and atmosphere surrounding us which changes from day to day; equal to 14.7 psia.

Attainment area: A geographic region where the concentration of a specific air pollutant does not exceed federal standards.

Auger: A rotating, screw-type device that moves material through a cylinder.

Available production capacity: The biodiesel production capacity of refining facilities that are not specifically designed to produce biodiesel.

Average megawatt (MWa or aMW): One megawatt of capacity produced continuously over a period of one year; 1 aMW = 1 MW × 8760 hours/year = 8,760 MWh = 8,760,000 kWh.

B100: Another name for pure biodiesel.

Background level: The average amount of a substance present in the environment. Originally referring to naturally occurring phenomena; used in toxic substance monitoring.

Backup rate: A utility charge for providing occasional electricity service to replace on-site generation.

Backup electricity: Power or services needed occasionally; for example, when on-site generation equipment fails.

Baffle chamber: In incinerator design, a chamber designed to settle fly ash and coarse particulate matter by changing the direction and reducing the velocity of the combustion gases.

Bagasse: Sugarcane waste.

Bark: The outer protective layer of a tree outside the cambium comprising the inner bark and the outer bark; the inner bark is a layer of living bark that separates the outer bark from the cambium and in a living tree is generally soft and moist; the outer bark is a layer of dead bark that forms the exterior surface of the tree stem; the outer bark is frequently dry and corky.

Barrel (bbl): the unit of measure used by the petroleum industry; equivalent to approximately forty-two US gallons or approximately thirty four (33.6) Imperial gallons or 159 liters; 7.2 barrels are equivalent to one tonne of oil (metric).

Barrel of oil equivalent (BOE): A unit of energy equal to the amount of energy contained in a barrel of crude oil; approximately 5.78 million Btu or 1,700 kWh; one barrel equals 5.6 cubic feet or .159 cubic meters; for crude oil, one barrel is about 0.136 metric tons, 0.134 long tons, and 0.150 short tons; a barrel is a liquid measure equal to 42 gallons or about 306 pounds.

Base: A classification of substances which when combined with an acid will form a salt plus water, usually producing hydroxide ions when dissolved.

Baseline: A projected level of future emissions against which reductions by project activities might be determined, or the emissions that would occur without policy intervention.

Baseload capacity: The power output that generating equipment can continuously produce.

Baseload Demand: The minimum demand experienced by an electric utility, usually 30-40 percent of the utility´s peak demand.

Batch distillation: A process in which the liquid feed is placed in a single container and the entire volume is heated, in contrast to continuous distillation in which the liquid is fed continuously through the still.

Batch fermentation: Fermentation conducted from start to finish in a single vessel; see Fermentation.

Batch process: Unit operation where one cycle of feedstock preparation, cooking, fermentation and distillation is completed before the next cycle is started.

Beer: A general term for all fermented malt beverages flavored with hops; a low level (6 to 12 percent) alcohol solution derived from the fermentation of mash by microorganisms.

Beer still: The stripping section of a distillation column for concentrating ethanol.

Benchmarking: A process to assess relative performance among a group of peers; a means to establish allocations of emissions allowances.
Benzene: A toxic, six-carbon aromatic component of gasoline; a known carcinogen.
Billion: 1×10^9
Biobutanol: Alcohol containing four carbon atoms per molecule, produced from the same feedstocks as ethanol, but with a modified fermentation and distillation process; less water-soluble than ethanol, biobutanol has a higher energy density and can be transported by pipeline more easily.
Biochemical conversion: The use of fermentation or anaerobic digestion to produce fuels and chemicals from organic sources.
Biochemical conversion process: The use of living organisms or their products to convert organic material to fuels, chemicals or other products.
Biochemical oxygen demand (BOD): A standard means of estimating the degree of water pollution, especially of water bodies that receive contamination from sewage and industrial waste; the amount of oxygen needed by bacteria and other microorganisms to decompose organic matter in water – the greater the BOD, the greater the degree of pollution; biochemical oxygen demand is a process that occurs over a period of time and is commonly measured for a five-day period, referred to as BOD5.
Bioconcentration (Bioaccumulation): The accumulation of a chemical in tissues of an organism to levels greater than in the environment in which the organism lives.
Biodegradable: Capable of decomposing rapidly under natural conditions.
Biodiesel: A fuel derived from biological sources that can be used in diesel engines instead of petroleum-derived diesel; hrough the process of transesterification, the triglycerides in the biologically derived oils are separated from the glycerin, creating a clean-burning, renewable fuel.
Biodiesel blend: A blend of biodiesel and diesel fuel – the blend can be with Diesel #1, Diesel #2, or JP8; one standard blend that meets the minimum requirements of the federal EPA Clean Air Act criteria is B20. The number after "B" indicates the percentage of biodiesel included in the blend - in B20, there would be 20 percent biodiesel and 80 percent diesel in the fuel blend; a biodiesel blend can come in any mixture percentage, such as B2, B5, B50, and B85.
Biodiesel recipe: The most common recipe uses waste vegetable oil (WVO), methanol (wood alcohol), and sodium hydroxide (caustic soda/lye) to produce biodiesel and glycerin; the steps are: (1) cleaning/heating waste vegetable oil, (2) titration of the waste vegetable oil sample, (3) combining methanol and sodium hydroxide in exact amounts, (4) combining (3) with (1) and mixing at 50°C, (5) settling (6) separating the biodiesel from the wastes, (7) washing and drying the biodiesel, (8) disposing of wastes.
Bioenergy: Useful, renewable energy produced from organic matter - the conversion of the complex carbohydrates in organic matter to energy; organic matter may either be used directly as a fuel, processed into liquids and gasses, or be a residual of processing and conversion.

Bioethanol: Ethanol produced from biomass feedstocks; includes ethanol produced from the fermentation of crops, such as corn, as well as cellulosic ethanol produced from woody plants or grasses.

Biofuels: a generic name for liquid or gaseous fuels that are not derived from petroleum based fossils fuels or contain a proportion of non fossil fuel; fuels produced from plants, crops such as sugar beet, rape seed oil or re-processed vegetable oils or fuels made from gasified biomass; fuels made from renewable biological sources and include ethanol, methanol, and biodiesel; sources include, but are not limited to: corn, soybeans, flaxseed, rapeseed, sugarcane, palm oil, raw sewage, food scraps, animal parts, and rice.

Biogas: A combustible gas derived from decomposing biological waste under anaerobic conditions. Biogas normally consists of 50 to 60 percent methane. See also landfill gas.

Bioheat: A name sometimes applied to biodiesel when its application is for heating purposes.

Biological assessment: A specific process required as part of an environmental assessment; an evaluation of potential effects of a proposed project on proposed, endangered, threatened and sensitive animal and plant species and their habitats.

Biological oxidation: Decomposition of organic materials by microorganisms.

Biomass: Any organic matter that is available on a renewable or recurring basis, including agricultural crops and trees, wood and wood residues, plants (including aquatic plants), grasses, animal manure, municipal residues, and other residue materials. Biomass is generally produced in a sustainable manner from water and carbon dioxide by photosynthesis. There are three main categories of biomass - primary, secondary, and tertiary.

Biomass fuel: Liquid, solid or gaseous fuel produced by conversion of biomass.

Biomass processing residues: Byproducts from processing all forms of biomass that have significant energy potential; the residues are typically collected at the point of processing, they can be convenient and relatively inexpensive sources of biomass for energy.

Bio-naphtha: A term used in some eastern European nations for biodiesel.

Biopower: The use of biomass feedstock to produce electric power or heat through direct combustion of the feedstock, through gasification and then combustion of the resultant gas, or through other thermal conversion processes. Power is generated with engines, turbines, fuel cells, or other equipment.

Bioreactor: A vessel in which a chemical process occurs, which usually involves organisms or biochemically active substances derived from such organisms.

Biorefinery - A facility that processes and converts biomass into value-added products. These products can range from biomaterials to fuels such as ethanol or important feedstocks for the production of chemicals and other materials.

Biomass to liquid (BTL, BtL): The process of converting biomass to liquid fuels. Hmm, that seems painfully obvious when you write it out.

Boiler: Any device used to burn biomass fuel to heat water for generating steam.

Boiler horsepower: A measure of the maximum rate of heat energy output of a steam generator; one boiler horsepower equals 33,480 Btu/hr output in steam.

Bone dry: Having zero percent moisture content. Wood heated in an oven at a constant temperature of 100°C (212°F) or above until its weight stabilizes is considered bone dry or oven dry.

Bottoming cycle: A cogeneration system in which steam is used first for process heat and then for electric power production.

Black liquor: Solution of lignin-residue and the pulping chemicals used to extract lignin during the manufacture of paper.

Brewing: Generically, the entire beer-making process, but technically only the part of the process during which the beer wort is cooked in a brew kettle and during which time the hops are added; after brewing the beer is fermented.

British thermal unit (BTU): (Btu) A non-metric unit of heat, still widely used by engineers; One Btu is the heat energy needed to raise the temperature of one pound of water from 60°F to 61°F at one atmosphere pressure. 1 Btu = 1055 joules (1.055 kJ).

BTL (BtL): biomass to liquids.

Brown grease: Waste grease that is the least expensive of the various grades of waste grease.

Bubble wash: A method of final washing of biodiesel through air agitation. Biodiesel floats above a quantity of water; bubbles from an aquarium air pump and air stone are injected into the water causing the bubbles to rise – at the water/biodiesel interface, the air bubbles carry water up through the biodiesel by surface tension, simple diffusion causes water soluble impurities in the biodiesel to be extracted into the water, as the bubble reaches the surface and breaks, the water is freed and percolates back down through the biodiesel again.

Bunker - A storage tank.

Butanol: Though generally produced from fossil fuels, this four-carbon alcohol can also be produced through bacterial fermentation of alcohol.

By-product: A substance, other than the principal product, generated as a consequence of creating a biofuel.

COD: Chemical oxygen demand.

Canola: see Rapeseed.

Capacity: The maximum power that a machine or system can produce or carry safely; the maximum instantaneous output of a resource under specified conditions – the capacity of generating equipment is generally expressed in kilowatts or megawatts.

Capacity factor: The amount of energy that a power plant actually generates compared to its maximum rated output, expressed as a percentage.

Capital cost: The total investment needed to complete a project and bring it to a commercially operable status; the cost of construction of a new plant; the expenditures for the purchase or acquisition of existing facilities.

Carbohydrate: A chemical compound made up of carbon, hydrogen, and oxygen; includes sugars, cellulose, and starches.

Carbon chain: The atomic structure of hydrocarbons in which a series of carbon atoms, saturated by hydrogen atoms, form a chain; volatile oils have shorter chains while fats have longer chain lengths, and waxes have extremely long carbon chains.

Carbon cycle: The natural processes that govern the exchange of carbon (in the form of carbon dioxide gas, carbonates and organic compounds) among the atmosphere, ocean and terrestrial systems. Major components include photosynthesis, respiration and decay between atmospheric and terrestrial, thermodynamic invasion and evasion between the ocean and atmosphere, operation of the carbon pump and mixing in the deep ocean. Over still longer periods, the geological processes of outgassing, volcanism, sedimentation and weathering are also important.

Carbon dioxide (CO_2): A product of combustion that acts as a greenhouse gas in the Earth's atmosphere, trapping heat and contributing to climate change.

Carbon monoxide (CO): A lethal gas produced by incomplete combustion of carbon-containing fuels in internal combustion engines. It is colorless, odorless, and tasteless. (As in flavorless, we mean, though it's also been known to tell a bad joke or two.)

Carbon sequestration: The storage of carbon or carbon dioxide in the forests, soils, ocean, or underground in depleted oil and gas reservoirs, coal seams and saline aquifers. Examples include: the separation and storage of carbon dioxide from flue gases or the processing of fossil fuels to produce hydrogen; and the direct removal of carbon dioxide from the atmosphere through land-use change, afforestation, reforestation, ocean fertilization, and agricultural practices to enhance the carbon content of soil.

Carbon sink: a geographical area whose vegetation and/or soil soaks up significant carbon dioxide from the atmosphere; such areas, typically in tropical regions, are increasingly being sacrificed for energy crop production.

Catalyst: A substance that accelerates a chemical reaction without itself being affected. In refining, catalysts are used in the cracking process to produce blending components for fuels.

Cellulose: Fiber contained in leaves, stems, and stalks of plants and trees; most abundant organic compound on earth; it is a polymer of glucose with a repeating unit of $C_6H_{10}O_5$ strung together by ß-glycosidic linkages – the ß-linkages in cellulose form linear chains that are highly stable and resistant to chemical attack because of the high degree of hydrogen bonding that can occur between chains of cellulose; hydrogen bonding between cellulose chains makes the polymers more rigid, inhibiting the flexing of the molecules that must occur in the hydrolytic breaking of the glycosidic linkages - hydrolysis can reduce cellulose to a cellobiose repeating unit, $C_{12}H_{22}O_{11}$, and ultimately to the six-carbon sugar glucose, $C_6H_{12}O_6$.

Cetane number: A measure of the ignition quality of diesel fuel; the higher the number the more easily the fuel is ignited under compression.

Cetane rating: Measure of the combustion quality of diesel fuel.

Chips: Small fragments of wood chopped or broken by mechanical equipment – total tree chips include wood, bark, and foliage while pulp chips or clean chips are free of bark and foliage.

Chlorofluorocarbon: A family of chemicals composed primarily of carbon, hydrogen, chlorine, and fluorine; used principally as refrigerants and industrial cleansers and have the tendency to destroy the Earth's protective ozone layer.

Clarifier: A tank used to remove solids by gravity, to remove colloidal solids by coagulation, and to remove floating oil and scum through skimming.

Class I Area: Any area designated for the most stringent protection from air quality degradation.

Class II Area: Any area where air is cleaner than required by federal air quality standards and designated for a moderate degree of protection from air quality degradation; moderate increases in new pollution may be permitted in Class II areas.

Clean Air Act (CAA): US national law establishing ambient air quality emission standards to be implemented by participating states; originally enacted in 1963, the CAA has been amended several times, most recently in 1990 and includes vehicle emission standards regulating the emission of criteria pollutants (lead, ozone, carbon monoxide, sulfur dioxide, nitrogen oxides and particulate matter); the 1990 amendments added reformulated gasoline (RFG) requirements and oxygenated gasoline provisions.

Clean fuels: Fuels such as E-10 (unleaded) that burn cleaner and produce fewer harmful emissions compared to ordinary gasoline.

Climate Change: A change of climate due to the place of the Earth between glacial periods (inter-glacial period) – the Earth is currently in an inter-glacial period and I warming due to this; also a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods.

Closed-loop biomass: Crops grown, in a sustainable manner, for the purpose of optimizing their value for bioenergy and bioproduct uses. This includes annual crops such as maize and wheat, and perennial crops such as trees, shrubs, and grasses such as switch grass.

Cloud Point: The temperature at which the first wax crystals appear and a standardized ASTM test protocol is used to determine this temperature.

Coarse materials: Wood residues suitable for chipping, such as slabs, edgings, and trimmings.

Cogeneration: The sequential production of electricity and useful thermal energy from a common fuel source.

Colloid: A stable system of small particles dispersed in another phase; a multiphase system in which one dimension of a dispersed phase is of colloidal size; colloids are the liquid and solid forms of aerosols, foams, emulsions, and suspensions within the colloidal size class.

Colloidal size: 0.001 micron to 1 micron in any dimension; dispersions where the particle size is in this range are referred to as colloidal aerosols, colloidal emulsions, colloidal foams, or colloidal suspensions.

Colza: Eurasian plant cultivated for its seed and as a forage crop.

Combustion burning: The transformation of biomass fuel into heat, chemicals, and gases through chemical combination of hydrogen and carbon in the fuel with oxygen in the air.

Combustion gases: The gases released from a combustion process.

Compound: A chemical term denoting a combination of two or more distinct elements.

Compressed natural gas (CNG): Natural gas that has been compressed under high pressure (typically 2000 to 3600 psi).

Compression ignition engine (CI engine): An engine in which the fuel is ignited by high temperature caused by extreme pressure in the cylinder, rather than by a spark from a spark plug; a diesel engine.

Concentrated acid hydrolysis: A method of converting biomass into cellulosic ethanol.

Conditional use permit: A permit, with conditions, allowing an approved use on a site outside the appropriate zoning class.

Conservation: Efficiency of energy use, production, transmission, or distribution that results in a decrease of energy consumption while providing the same level of service.

Continuous fermentation: A steady state fermentation system that operates without interruption; each stage of fermentation occurs in a separate section of the fermenter, and flow rates are set to correspond with required residence times.

Continuous flow process: A general term for any number of biodiesel production processes that involves the continuous addition of ingredients to produce biodiesel on a continual, round-the-clock basis, as opposed to the batch process.

Conventional biofuels: Biofuels such as bioethanol and biodiesel, which are typically made from corn, sugarcane and beet, wheat or oilseed crops such as soy and rapeseed oil.

Conventional crude oil (conventional petroleum): crude oil that is pumped from the ground and recovered using the energy inherent in the reservoir; also recoverable by application of secondary recovery techniques.

Conversion efficiency: A comparison of the useful energy output to the potential energy contained in the fuel; the efficiency calculation relates to the form of energy produced and allows a direct comparison of the efficiency of different conversion processes can be made only when the processes produce the same form of energy output.

Cooker: A tank or vessel designed to cook a liquid or extract or digest solids in suspension; the cooker usually contains a source of heat; and is fitted with an agitator.

Cord: A stack of wood comprising 128 cubic feet (3.62 m^3); standard dimensions are $4 \times 4 \times 8$ feet, including air space and bark. One cord contains approx. 1.2 U.S. tons (oven-dry) = 2400 pounds = 1089 kg.

Corn Stover: Residue materials from harvesting corn consisting of the cob, leaves and stalk.

Cracking: A secondary refining process that uses heat and/or a catalyst to break down high molecular weight chemical components into lower molecular weight products which can be used as blending components for fuels.

Cropland: Total cropland includes five components: cropland harvested, crop failure, cultivated summer fallow, cropland used only for pasture, and idle cropland.

Crude oil: see Petroleum.

Cropland pasture: Land used for long-term crop rotation. However, some cropland pasture is marginal for crop uses and may remain in pasture indefinitely. This category also includes land that was used for pasture before crops reached maturity and some land used for pasture that could have been cropped without additional improvement.

Cull tree: A live tree, 5.0 inches in diameter at breast height (d.b.h., dbh) or larger that is non-merchantable for saw logs now or prospectively because of rot, roughness, or species. (See definitions for rotten and rough trees.)

Cultivated summer fallow: cropland cultivated for one or more seasons to control weeds and accumulate moisture before small grains are planted.

DDGS (Dried distillers grain with soluble constituents): A by-product of dry mill ethanol production that is fed to livestock.

Density: the mass (or weight) of a unit volume of any substance at a specified temperature; see also Specific gravity.

Desulfurization: the removal of sulfur or sulfur compounds from a process feedstock or process product.

Diesel engine: named for the German engineer Rudolph Diesel; this internal-combustion, compression-ignition engine works by heating fuels and causing them to ignite. It can use either petroleum or bio-derived fuel.

Diesel #1 and Diesel #2: Diesel #1 is also called kerosene and is not generally used as a fuel oil in diesel vehicles – it has a lower viscosity (it is thinner) than Diesel #2, which is the typical diesel vehicle fuel. Biodiesel replaces Diesel #2 or a percentage.

Diesel fuel: A distillate of fuel oil that has been historically derived from petroleum for use in internal combustion engines; can also be derived from plant and animal sources.

Diesel, Rudolph: German inventor famed for fashioning the diesel engine, which made its debut at the 1900 World's Fair; he initially intended the engine to run on vegetable-derived fuels, with the hope that farmers would be able to grow their own fuel sources.

Digester: An airtight vessel or enclosure in which bacteria decomposes biomass in water to produce biogas.

Direct-injection engine: a diesel engine in which fuel is injected directly into the cylinder; most of the newer models are *turbo direct injection*.

Distillate: Any petroleum product produced by boiling crude oil and collecting the vapors produced as a condensate in a separate vessel, for example gasoline (light distillate), gas oil (middle distillate), or fuel oil (heavy distillate).

Distillation: The primary distillation process which uses high temperature to separate crude oil into vapor and fluids which can then be fed into a distillation or fractionating tower.

Distillers grains: Byproduct of ethanol production that can be used to feed livestock; alternatively, distillers dried grains with soluble constituents (DDGS).

Dispersion: A stable or unstable system of fine particles, larger than colloidal size, evenly distributed in a medium.

Distillate Oil: Any distilled product of crude oil; a volatile petroleum product used for home heating and most machinery.

Distillation: The process to separate the components of a liquid mixture by boiling the liquid and then condensing the resulting vapor.

Downdraft gasifier: A gasifier in which the product gases pass through a combustion zone at the bottom of the gasifier.

Dry mill: An ethanol production process in which the entire corn kernel is first ground into flour before processing – in addition to ethanol, dry mills also produce dried distillers grains with soluble constituents (DDGS) which is fed to livestock; and carbon dioxide which is used in food processing and bottling; most new ethanol plants are dry mill facilities.

Dry ton: 2,000 pounds of material dried to a constant weight.

Dutch oven furnace: One of the earliest types of furnaces, having a large, rectangular box lined with firebrick (refractory) on the sides and top; commonly used for burning wood.

DME: Dimethyl ether.

E10: An alcohol fuel mixture containing 10 percent ethanol and 90 percent gasoline by volume.

E85: An alcohol fuel mixture containing 85 percent ethanol and 15 percent gasoline by volume, and the current alternative fuel of choice of the US government.

Ecology: The study of the interrelationships between organisms and their environment.

E-diesel: A blend of ethanol and diesel fuel plus other additives designed to reduce air pollution from heavy equipment, city buses and other vehicles that operate on diesel engines.

Effluent: The liquid or gas discharged from a process or chemical reactor, usually containing residues from that process.

Elemental Analysis: The determination of carbon, hydrogen, nitrogen, oxygen, sulfur, chlorine and ash in a sample.

Emission Offset: A reduction in the air pollution emissions of existing sources to compensate for emissions from new sources.

Emissions: Substances discharged into the air during combustion, e.g., all that stuff that comes out of your car.

Emulsification: To emulsify; to form an emulsion.

Emulsion: A suspension of small drops of 1 liquid in a 2nd with which the 1st will not mix; can be formed either by mechanical agitation, or by chemical processes; unstable emulsions will separate with time or temperature but stable emulsions will not separate.

Energy balance: The difference between the energy produced by a fuel and the energy required to obtain it through agricultural processes, drilling, refining, and transportation.

Energy crops: crops grown specifically for their fuel value; include food crops such as corn and sugarcane, and nonfood crops such as poplar trees and switch grass; energy crops are under development in the United States: short-rotation woody crops, which are fast-growing hardwood trees harvested in 5 to 8 years, and herbaceous energy crops, such as perennial grasses, which are harvested annually after taking 2 to 3 years to reach full productivity.

Energy-efficiency ratio: A number representing the energy stored in a fuel as compared to the energy required to produce, process, transport, and distribute that fuel.

Environment: The external conditions that affect organisms and influence their development and survival.

Environmental assessment (EA): A public document that analyzes a proposed federal action for the possibility of significant environmental impacts – if the environmental impacts will be significant, the federal agency must then prepare an environmental impact statement.

Environmental impact statement (EIS): A statement of the environmental effects of a proposed action and of alternative actions. Section 102 of the National Environmental Policy Act requires an EIS for all major federal actions.

Enzymatic hydrolysis: A process by which enzymes (biological catalysts) are used to break down starch or cellulose into sugar.

Enzyme: A protein or protein-based molecule that speeds up chemical reactions occurring in living things; enzymes act as catalysts for a single reaction, converting a specific set of reactants into specific products.

Esters: Any of a large group of organic compounds formed when an acid and alcohol is mixed; methyl acetate (CH_3COOCH_3) is the simplest ester; biodiesel contains methyl stearate.

ETBE: see Ethyl Tertiary Butyl Ether.

Ethanol (ethyl alcohol, alcohol, or grain-spirit): A clear, colorless, flammable oxygenated hydrocarbon; used as a vehicle fuel by itself (E100 is 100% ethanol by volume), blended with gasoline (E85 is 85% ethanol by volume), or as a gasoline octane enhancer and oxygenate (10% by volume).

Ethers: Liquid fuel made from a blending an alcohol with isobutylene.

Ethyl tertiary butyl ether (ethyl t-butyl ether): Ether created from ethanol that can increase octane and reduce the volatility of gasoline, decreasing evaporation and smog formation.

Evaporation: The conversion of a liquid to the vapor state by the addition of latent heat or vaporization.

Extractives: Any number of different compounds in biomass that are not an integral part of the cellular structure – the compounds can be extracted from wood by means of polar and non-polar solvents including hot or cold water, ether, benzene, methanol, or other solvents that do not degrade the biomass structure and the types of extractives found in biomass samples are entirely dependent upon the sample itself.

FAAE: A term for biodiesel made from any alcohol during its production process.

FAME (fatty acid methyl ester): ester that can created by a catalyzed reaction between fatty acids and methanol; the constituents in biodiesel are primarily FAMEs, usually obtained from vegetable oils by transesterification.

Fast pyrolysis: Thermal conversion of biomass by rapid heating to between 450 to 600°C (842 to 1,112°F) in the absence of oxygen

Fatty acid: A carboxylic acid (an acid with a -COOH group) with long hydrocarbon side chains; feedstocks are first converted to fatty acids and then to biodiesel by transesterification.

Fatty Acid Alkyl Ester: see FAAE.

Fatty acid methyl ester: see FAME.

Feedstock: Raw material used in an industrial process; biomass used in the creation of a biofuel (e.g., corn or sugarcane for ethanol, soybeans or rapeseed for biodiesel).

Fermentation: Conversion of carbon-containing compounds by micro-organisms for production of fuels and chemicals such as alcohols, acids or energy-rich gases.

FFV: see Flexible-fuel Vehicle.

Fiber products; Products derived from fibers of herbaceous and woody plant materials; examples include pulp, composition board products, and wood chips for export.

Fine materials: Wood residues not suitable for chipping, such as planer shavings and sawdust.

Fischer-Tropsch Process: process for producing liquid fuels, usually diesel fuel, from natural gas or synthetic gas from gasified coal or biomass.

Fixed carbon: The carbonaceous residue remaining after heating in a prescribed manner to decompose thermally unstable components and to distill volatiles; part of the proximate analysis group.

Flashpoint: The lowest temperature at which a liquid will produce enough vapor to ignite, if the vapor is flammable.

Flexible-fuel vehicle (flex-fuel vehicle): A vehicle that can run alternately on two or more sources of fuel; includes cars capable of running on gasoline and gasoline/ethanol mixtures, as well as cars that can run on both gasoline and natural gas.

Fluid coking: a continuous fluidised solids process that cracks feed thermally over heated coke particles in a reactor vessel to gas, liquid products, and coke.

Fluidized-bed boiler: A large, refractory-lined vessel with an air distribution member or plate in the bottom, a hot gas outlet in or near the top, and some provisions for introducing fuel; the fluidized bed is formed by blowing air up through a layer of inert particles (such as sand or limestone) at a rate that causes the particles to go into suspension and continuous motion; the super-hot bed material increased combustion efficiency by its direct contact with the fuel.

Fly ash: Small ash particles carried in suspension in combustion products.

Foam: A dispersion of a gas in a liquid or solid.

Forest health: A condition of ecosystem sustainability and attainment of management objectives for a given forest area; usually considered to include green trees, snags, resilient stands growing at a moderate rate, and endemic levels of insects and disease.

Forest land: Land at least 10 percent stocked by forest trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated; includes transition zones, such as areas between heavily forested and non-forested lands that are at least 10 percent stocked with forest trees and forest areas adjacent to urban and built-up lands; also included are pinyon-juniper and chaparral areas; minimum area for classification of forest land is 1 acre.

Forest residues: Material not harvested or removed from logging sites in commercial hardwood and softwood stands as well as material resulting from forest management operations such as precommercial thinnings and removal of dead and dying trees.

Fossil fuel: Solid, liquid, or gaseous fuels formed in the ground after millions of years by chemical and physical changes in plant and animal residues under high temperature and pressure. Oil, natural gas, and coal are fossil fuels.

Fuel cell: A device that converts the energy of a fuel directly to electricity and heat, without combustion.

Fuel cycle: The series of steps required to produce electricity. The fuel cycle includes mining or otherwise acquiring the raw fuel source, processing and cleaning the fuel, transport, electricity generation, waste management and plant decommissioning.

Fuel oil: A heavy residue, black in color, used to generate power or heat by burning in furnaces.

Fuel treatment evaluator (FTE): A strategic assessment tool capable of aiding the identification, evaluation, and prioritization of fuel treatment opportunities.

Fuel wood - Wood used for conversion to some form of energy, primarily for residential use.

Furnace: An enclosed chamber or container used to burn biomass in a controlled manner to produce heat for space or process heating.

Galactan: The polymer of galactose with a repeating unit of $C_6H_{10}O_5$; found in hemicellulose it can be hydrolyzed to galactose.

Galactose: A six-carbon sugar with the formula $C_6H_{12}O_6$; a product of hydrolysis of galactan found in the hemicellulose fraction of biomass.

Gas engine: A piston engine that uses natural gas rather than gasoline – fuel and air are mixed before they enter cylinders; ignition occurs with a spark.

Gaseous emissions: Substances discharged into the air during combustion, typically including carbon dioxide, carbon monoxide, water vapor, and hydrocarbons.

Gasification: A chemical or heat process used to convert carbonaceous material (such as coal, petroleum, and biomass) into gaseous components such as carbon monoxide and hydrogen.

Gasifier: A device for converting solid fuel into gaseous fuel; in biomass systems, the process is referred to as *pyrolysis distillation* or *pyrolytic distillation*.

Gasohol: A mixture of 10% anhydrous ethanol and 90% gasoline by volume; 7.5% anhydrous ethanol and 92.5% gasoline by volume; or 5.5% anhydrous ethanol and 94.5% gasoline by volume.

Gasoline: A volatile, flammable liquid obtained from petroleum that has a boiling range of approximately 30 to 220°C 86 to 428°F) and is used for fuel for spark-ignition internal combustion engines.

Gas shift process: A process in which carbon monoxide and hydrogen react in the presence of a catalyst to form methane and water.

Gas to liquids (GTL, GtL): The process of refining natural gas and other hydrocarbons into longer-chain hydrocarbons, which can be used to convert gaseous waste products into fuels.

Gas turbine (combustion turbine): A turbine that converts the energy of hot compressed gases (produced by burning fuel in compressed air) into mechanical power – often fired by natural gas or fuel oil.

Gas to liquids (GTL): The process of refining natural gas and other hydrocarbons into longer-chain hydrocarbons, which can be used to convert gaseous waste products into fuels.

Gel point: The point at which a liquid fuel cools to the consistency of petroleum jelly.

Genetically modified organism (GMO): An organism in which the genetic material has been modified through recombinant DNA technology, which alters the phenotype of the organism to meet desired specifications.

Global warming: The observed increase in global average surface temperature. Often (poorly) used as a synonym for *climate change*, which is a more accurate definition of the wider impacts of greenhouse gases on the climate and the effect of an inter-glacial period.

Glycerin ($CH_2OH.CHOH.CH_2OH$): A byproduct of biodiesel production; each of the hydroxyl (OH) functions is one of the three places where an ester is broken off of the triglyceride molecule (e.g., vegetable oil).

Glycerin (Glycerine, Glycerol): A liquid by-product of biodiesel production; used in the manufacture of dynamite, cosmetics, liquid soaps, inks, and lubricants.

Grain Alcohol: See Ethanol.

Grassland pasture and range: All open land used primarily for pasture and grazing, including shrub and brush land types of pasture; grazing land with sagebrush and scattered mesquite; and all tame and native grasses, legumes, and

other forage used for pasture or grazing; because of the diversity in vegetative composition, grassland pasture and range are not always clearly distinguishable from other types of pasture and range; at one extreme, permanent grassland may merge with cropland pasture, or grassland may often be found in transitional areas with forested grazing land.

Grease car (greasecar): A diesel-powered automobile rigged post-production to run on used vegetable oil.

Greenhouse effect: The effect of certain gases in the Earth's atmosphere in trapping heat from the sun.

Greenhouse gases: Gases that trap the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major greenhouse gases are water vapor and carbon dioxide. Other greenhouse gases include methane, ozone, chlorofluorocarbons, and nitrous oxide.

Grid: An electric utility company's system for distributing power.

Gross heating value (GHV): The maximum potential energy in the fuel as received, considering moisture content (MC).

Growing stock: A classification of timber inventory that includes live trees of commercial species meeting specified standards of quality or vigor; cull trees are excluded.

GTL (GtL, Gas to liquid): a refinery process which converts natural gas into longer-chain hydrocarbons; gas can be converted to liquid fuels via a direct conversion or using a process such as the Fischer-Tropsch process.

Habitat: The area where a plant or animal lives and grows under natural conditions. Habitat includes living and non-living attributes and provides all requirements for food and shelter.

Hardwood: One of the botanical groups of dicotyledonous trees that have broad leaves in contrast to the conifers or softwoods – the term has no reference to the actual hardness of the wood – the botanical name for hardwoods is angiosperms; short-rotation, fast growing hardwood trees are being developed as future energy crops which are uniquely developed for harvest from 5 to 8 years after planting and example include: hybrid poplars (Populus sp.), hybrid willows (Salix sp.), silver maple (Acer saccharinum), and black locust (Robinia pseudoacacia).

Heating value: The maximum amount of energy that is available from burning a substance; see Gross Heating Value.

Heavy (crude) oil: oil that is more viscous that conventional crude oil, has a lower mobility in the reservoir but can be recovered through a well from the reservoir by the application of a secondary or enhanced recovery methods.

Hectare: Common metric unit of area, equal to 2.47 acres. 100 hectares = 1 square kilometer.

Hemicellulose: Consists of short, highly branched chains of sugars in contrast to cellulose, which is a polymer of only glucose, hemicellulose is a polymer of five different sugars; contains five-carbon sugars (usually D-xylose and

L-arabinose) and six-carbon sugars (D-galactose, D-glucose, and D-mannose) and uronic acid which are highly substituted with acetic acid; the branched nature of hemicellulose renders it amorphous and relatively easy to hydrolyze to its constituent sugars compared to cellulose; when hydrolyzed, the hemicellulose from hardwoods releases products high in xylose (a five-carbon sugar); hemicellulose contained in softwoods, by contrast, yields more six-carbon sugars.

Herbaceous: Non-woody type of vegetation, usually lacking permanent strong stems, such as grasses, cereals and canola (rape).

Herbaceous energy crops: Perennial non-woody crops that are harvested annually, though they may take 2 to 3 years to reach full productivity; examples include: switch grass (*Panicum virgatum*), reed canary grass (*Phalaris arundinacea*), miscanthus (*Miscanthus x giganteus*), and giant reed (*Arundo donax*).

Herbaceous plants: Non-woody species of vegetation, usually of low lignin content such as grasses.

Heteroatom compounds: chemical compounds that contain nitrogen and/or oxygen and/or sulfur and /or metals bound within their molecular structure(s).

Hexose: Any of various simple sugars that have six carbon atoms per molecule (e.g. glucose, mannose, and galactose).

Higher heating value (HHV): The potential combustion energy when water vapor from combustion is condensed to recover the latent heat of vaporization. Lower heating value (LHV) is the potential combustion energy when water vapor from combustion is not condensed.

Hydrocarbon: A chemical compound that contains a carbon backbone with hydrogen atoms attached to that backbone.

Hydrocarbonaceous material: a material such as tar sand bitumen that is composed of carbon and hydrogen with other elements (heteroelements) such as nitrogen, oxygen, sulfur, and metals chemically combined within the structures of the constituents; even though carbon and hydrogen may be the predominant elements, there may be very few true hydrocarbons (q.v.).

Hydrocarbon compounds: chemical compounds containing only carbon and hydrogen.

Hydrodesulfurization: the removal of sulfur by hydrotreating.

Hydrogenation: Chemical reaction of a substance with molecular hydrogen, usually in the presence of a catalyst; a common hydrogenation is the hardening of animal fats or vegetable oils to make them solid at room temperature and improve their stability; hydrogen is added (in the presence of a nickel catalyst) to carbon-carbon double bonds in the unsaturated fatty acid portion of the fat or oil molecule.

Hydroprocesses: Refinery processes designed to add hydrogen to various products of refining.

Hydrotreating: Removal of heteroatomic (nitrogen, oxygen, and sulfur) species by treatment of a feedstock or product at relatively low temperatures in the presence of hydrogen.

Idle cropland: Land in which no crops were planted; acreage diverted from crops to soil-conserving uses (if not eligible for and used as cropland pasture) under federal farm programs is included in this component.

Incinerator: Any device used to burn solid or liquid residues or wastes as a method of disposal.

Inclined grate: A type of furnace in which fuel enters at the top part of a grate in a continuous ribbon, passes over the upper drying section where moisture is removed, and descends into the lower burning section. Ash is removed at the lower part of the grate.

Indirect-injection engine: An older model of diesel engine in which fuel is injected into a pre-chamber, partly combusted, and then sent to the fuel-injection chamber.

Indirect liquefaction: Conversion of biomass to a liquid fuel through a synthesis gas intermediate step.

Industrial wood: All commercial round wood products except fuel wood.

Interglacial period (or alternatively *interglacial*): A geological interval of warmer global average temperature lasting thousands of years that separates consecutive glacial periods within an *ice age*; the current Holocene interglacial period has persisted since the end of the Pleistocene, approximately 11,400 years ago.

Iodine value: a measure of the number of unsaturated carbon-carbon double bonds in a vegetable oil molecule – double bonds can allow polymerization, leading to the formation of lacquers and possibly blockage and damage to engine or fuel train components; in liquid biofuel applications the iodine value gives a lower cold filter plugging point (CFPP) or cloud point.

Jatropha: A non-edible evergreen shrub found in Asia, Africa and the West Indies; the seeds contain a high proportion of oil which can be used for making biodiesel.

Joule: Metric unit of energy, equivalent to the work done by a force of one Newton applied over distance of one meter (= 1 kg m2/s2). One joule (J) = 0.239 calories (1 calorie = 4.187 J).

Kerosene: A light middle distillate that in various forms is used as aviation turbine fuel or for burning in heating boilers or as a solvent, such as white spirit.

Kilowatt: (kW): A measure of energy equivalent to the expenditure of one kilowatt for one hour. For example, 1 kWh will light a 100-watt light bulb for 10 hours. 1 kWh = 3412 Btu.

Klason lignin: Lignin obtained from wood after the non-lignin components of the wood have been removed with a prescribed sulfuric acid treatment; a specific type of acid-insoluble lignin analysis.

Knock: Engine sound that results from ignition of the compressed fuel-air mixture prior to the optimal moment.

KOH: see Potassium hydroxide.

Landfill gas: A type of biogas that is generated by decomposition of organic material at landfill disposal sites. Landfill gas is approximately 50 percent methane. See also biogas.

Lignin: Structural constituent of wood and (to a lesser extent) other plant tissues which encrust the walls and cements the cells together; energy-rich material contained in biomass that can be used for boiler fuel.

Lignocellulose: Plant material made up primarily of lignin, cellulose, and hemicellulose.

Lignocellulose Technology: Technology that enables non-food biomass (e.g. fast growing willow, poplar and certain grasses) to be used as feedstock for ethanol production.

Lipid: Any of a group of organic compounds, including the fats, oils, waxes, sterols, and triglycerides, that are insoluble in water but soluble in nonpolar organic solvents, are oily to the touch, and together with carbohydrates and proteins constitute the principal structural material of living cells.

Live cull: A classification that includes live cull trees; when associated with volume, it is the net volume in live cull trees that are 5.0 inches in diameter and larger.

Logging residues: The unused portions of growing-stock and non-growing-stock trees cut or killed logging and left in the woods.

Lower heating value (LHV, Net Heat of Combustion): The heat produced by combustion of one unit of a substance, at atmospheric pressure under conditions such that all water in the products remains in the form of vapor; the net heat of combustion is calculated from the gross heat of combustion at 20°C (68°F) by subtracting 572 calories/gm (1030 Btu/lb) of water derived from one unit mass of sample, including both the water originally present as moisture and that formed by combustion – this subtracted amount is not equal to the latent heat of vaporization of water because the calculation also reduces the data from the gross value at constant volume to the net value at constant pressure and the appropriate factor for this reduction is 572 calories/gm.

Lye: see Sodium hydroxide.

M85: An alcohol fuel mixture containing 85 percent methanol and 15 percent gasoline by volume. Methanol is typically made from natural gas, but can also be derived from the fermentation of biomass.

Market barriers: Conditions that prevent or impede the diffusion of cost effective technologies or practices that would mitigate greenhouse gas emissions.

Market impacts: Impacts that are linked to market transactions and directly affect *gross domestic product* – for example, changes in the supply and price of agricultural goods. \

Market potential: The portion of the economic potential for greenhouse gas emissions reductions or energy-efficiency improvements that could be achieved under forecast market conditions, assuming no new policies and measures.

Megawatt: (MW) A measure of electrical power equal to one million watts (1,000 kW).

Methanol (methyl alcohol): A fuel typically derived from natural gas, but which can be produced from the fermentation of sugars in biomass.

Methoxide (Sodium methoxide, Sodium methylate, $CH_3O^- Na^+$): An organic salt, in pure form a white powder; in biodiesel production, methoxide is a product of mixing methanol and sodium hydroxide, yielding a solution of sodium methoxide in methanol, and a significant amount of heat; making sodium methoxide is the most dangerous step when making biodiesel.

Methyl alcohol: see Methanol.

Methyl Esters: see Biodiesel.

Million: 1×10^6

Mill residue: Wood and bark residues produced in processing logs into lumber, plywood, and paper.

Mitigation: Actions resulting in reductions to the degree or intensity of greenhouse gas emissions; also referred to as *abatement*.

Mitigative capacity: The ability of the social, political, and economic structures and conditions to undertake effective mitigation.

Modified/unmodified diesel engine: Traditional diesel engines must be modified to heat the diesel fuel oil before it reaches the fuel injectors in order to handle straight vegetable oil; any diesel engine modified to run on biodiesel.

Moisture: A measure of the amount of water and other components that are volatilized at 105°C (221°F) present in the biomass sample.

Moisture content: (MC): The weight of the water contained in wood, usually expressed as a percentage of weight, either oven-dry or as received.

Moisture content, dry basis: Moisture content expressed as a percentage of the weight of oven-wood, i.e.: [(weight of wet sample - weight of dry sample) / weight of dry sample] × 100.

Moisture content, wet basis: Moisture content expressed as a percentage of the weight of wood as-received, i.e.: [(weight of wet sample - weight of dry sample) / weight of wet sample] × 100.

Moisture free basis: Biomass composition and chemical analysis data is typically reported on a moisture free or dry weight basis – moisture (and some volatile matter) is removed prior to analytical testing by heating the sample at 105°C (221°F) to constant weight; by definition, samples dried in this manner are considered moisture free.

Monosaccharide: A simple sugar such as a five-carbon sugar (xylose, arabinose) or six-carbon sugar (glucose, fructose); sucrose, on the other hand is a disaccharide, composed of a combination of two simple sugar units, glucose and fructose.

MTBE: Methyl tertiary butyl ether is highly refined high octane light distillate used in the blending of petrol; used to increase octane number/rating and decrease the volatility of gasoline, decreasing evaporation and smog formation.

Municipal wastes: Residential, commercial, and institutional post-consumer wastes contain a significant proportion of plant-derived organic material that constitutes a renewable energy resource; waste paper, cardboard,

construction and demolition wood waste, and yard wastes are examples of biomass resources in municipal wastes.

Nitrogen fixation: The transformation of atmospheric nitrogen into nitrogen compounds that can be used by growing plants.

Nitrogen oxides (NOx): Products of combustion that contribute to the formation of smog and ozone.

Non-attainment area: Any area that does not meet the national primary or secondary ambient air quality standard established (by the Environmental Protection Agency) for designated pollutants, such as carbon monoxide and ozone.

Non-industrial private: An ownership class of private lands where the owner does not operate wood processing plants.

Non-forest land: Land that has never supported forests and lands formerly forested where use of timber management is precluded by development for other uses; if intermingled in forest areas, unimproved roads and non-forest strips must be more than 120 feet wide, and clearings, etc., must be more than 1 acre in area to qualify as non-forest land.

Non-market Impacts: Impacts that affect ecosystems or human welfare, but that are not directly linked to market transactions.

Octane number: Measure of a fuel's resistance to self-ignition; the octane number of a fuel is indicated on the pump – the higher the number, the slower the fuel burns; bioethanol typically adds two to three octane numbers when blended with ordinary petroleum – making it a cost-effective octane-enhancer; see Knock.

Oil from tar sand: synthetic crude oil.

Oil mining: application of a mining method to the recovery of bitumen.

OOIP (Oil originally in place or Original oil in place): the quantity of petroleum existing in a reservoir before oil recovery operations begin.

Open-loop biomass: Biomass that can be used to produce energy and bioproducts even though it was not grown specifically for this purpose; include agricultural livestock waste, residues from forest harvesting operations and crop harvesting.

Oxygenate: A substance which, when added to gasoline, increases the amount of oxygen in that gasoline blend; includes fuel ethanol, methanol, and methyl tertiary butyl ether (MTBE).

Oxygenated fuels: Fuels containing oxygen; ethanol is an oxygenate, meaning that it adds oxygen to the fuel mixture – more oxygen helps the fuel burn more completely thereby reducing the amount of harmful emissions from the tailpipe; a fuel such as ethanol-blended gasoline that contains a high oxygen content is called *oxygenated*.

Palm oil: A form of vegetable oil obtained from the fruit of the oil palm tree; widely used feedstock for traditional biodiesel production; the palm oil and

palm kernel oil are composed of fatty acids, esterified with glycerol just like any ordinary fat.

Particulate: A small, discrete mass of solid or liquid matter that remains individually dispersed in gas or liquid emissions.

Particulate emissions: particles of a solid or liquid suspended in a gas, or the fine particles of carbonaceous soot and other organic molecules discharged into the air during combustion.

Perennial: Plant that does not have to be planted every year as required for traditional row crops.

Petrodiesel: Petroleum-based diesel fuel usually referred to simply as diesel.

Petroleum: A hydrocarbon-based substance comprising of a complex blend of hydrocarbons derived from crude oil through the process of separation, conversion, upgrading, and finishing, including motor fuel, jet oil, lubricants, petroleum solvents, and used oil.

pH: A measure of acidity and alkalinity of a solution on a scale with 7 representing neutrality; lower numbers indicate increasing acidity, and higher numbers increasing alkalinity; each unit of change represents a tenfold change in acidity or alkalinity.

Photosynthesis: Process by which chlorophyll-containing cells in green plants concert incident light to chemical energy, capturing carbon dioxide in the form of carbohydrates.

Potassium hydroxide (KOH): used as a catalyst in the transesterification reaction to produce biodiesel.

Pour point: the lowest temperature at which oil will pour or flow when it is chilled without disturbance under definite conditions.

Primary wood-using mill: A mill that converts round wood products into other wood products; common examples are sawmills that convert saw logs into lumber and pulp mills that convert pulpwood round wood into wood pulp.

Process heat: Heat used in an industrial process rather than for space heating or other housekeeping purposes.

Producer gas: Fuel gas high in carbon monoxide (CO) and hydrogen (H2), produced by burning a solid fuel with insufficient air or by passing a mixture of air and steam through a burning bed of solid fuel.

Protein: A protein molecule is a chain of up to several hundred amino acids and is folded into a more or less compact structure; in the biologically active state, proteins function as catalysts in metabolism and to some extent as structural elements of cells and tissues; protein content in biomass (in mass percentage) can be estimated by multiplying the mass percentage nitrogen of the sample by 6.25.

Proximate analysis: The determination, by prescribed methods, of moisture, volatile matter, fixed carbon (by difference), and ash; the term proximate analysis does not include determinations of chemical elements or determinations other than those named and the group of analyses is defined in ASTM D3172.

Pulpwood: Round wood, whole-tree chips, or wood residues that are used for the production of wood pulp.

Pyrolysis: The thermal decomposition of biomass at high temperatures (greater than 400°F, or 200°C) in the absence of air; the end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), and gases (methane, carbon monoxide, and carbon dioxide) with proportions determined by operating temperature, pressure, oxygen content, and other conditions.

Pyrolysis oil: A bio-oil produced by fast pyrolysis of biomass; typically a dark brown, mobile liquid containing much of the energy content of the original biomass, with a heating value about half that of conventional fuel oil; conversion of raw biomass to pyrolysis oil represents a considerable increase in energy density and it can thus represent a more efficient form in which to transport it.

Quad: One quadrillion Btu (10^15 Btu) = 1.055 exajoules (EJ), or approximately 172 million barrels of oil equivalent.

Rapeseed (Brassica napus; rape, oilseed rape or canola: A bright yellow flowering member of the family Brassicaceae (mustard or cabbage family); a traditional feedstock used for biodiesel production; canola is a name taken from Canada oil due to the fact that much of the development of the oil was performed in Canada; see Colza.

Rapeseed oil: Food grade oil produced from rape seed is called Canola oil; see Colza.

Recovery boiler: A pulp mill boiler in which lignin and spent cooking liquor (black liquor) is burned to generate steam.

Reforestation: The act or process of re-establishing a forest on land that had been deforested in the last 50 years.

Refractory lining: A lining, usually of ceramic, capable of resisting and maintaining high temperatures.

Refuse-derived fuel (RDF): Fuel prepared from municipal solid waste; non-combustible materials such as rocks, glass, and metals are removed, and the remaining combustible portion of the solid waste is chopped or shredded.

Renewable fuels standard (RFS): Legislation enacted by United States Congress as part of the Energy Policy Act of 2005, requiring an increasing level of biofuels be used every year, rising to 7.5 billion gallons by 2012.

Residues: Bark and woody materials that are generated in primary wood-using mills when round wood products are converted to other products.

Residuum (pl. residua, also known as resid or resids): the non-volatile portion of petroleum that remains as residue after refinery distillation; hence, atmospheric residuum, vacuum residuum.

RIM: Refiner indicator margin.

Rotation: Period of years between establishment of a stand of timber and the time when it is considered ready for final harvest and regeneration.

Round wood products - Logs and other round timber generated from harvesting trees for industrial or consumer use.

RTFO (Renewable Transport Fuels Obligation): A United Kingdom policy that places an obligation on fuel suppliers to ensure that a certain percentage of the aggregate sale is made up of biofuels.

Saccaharification: The conversion of starch, for example, into sugar.

Saponification: The reaction of an ester with a metallic base and water (i.e., the making of soap); occurs when too much lye is used in biodiesel production.

Secondary wood processing mills: A mill that uses primary wood products in the manufacture of finished wood products, such as cabinets, moldings, and furniture.

Second generation biofuels: Biofuels produced from biomass or non-edible feedstocks.

Social Cost: Cost of an activity that includes the value of all the resources used in its provision – some of these are priced and others are not. Non-priced resources are referred to as externalities. It is the sum of the costs of these externalities and the priced resources that makes up the social cost. Decisions on social cost are value-weighted and require public policy decisions.

Sodium hydroxide (lye, caustic soda, NaOH): Strongly alkaline and extremely corrosive; mixing with fluids usually causes heat, and can create enough heat to ignite flammables (such as methanol); one of the main reactants for biodiesel production.

Softwood: Generally, one of the botanical groups of trees that in most cases have needle-like or scale-like leaves; the conifers; also the wood produced by such trees; the term has no reference to the actual softness of the wood; the botanical name for softwoods is gymnosperms.

Soy (Soy Oil): A vegetable oil pressed from soy beans.

Soy diesel: A general term for biodiesel which accentuates the renewable nature of biodiesel; popular in soy producing regions.

Spark ignition engine (SI engine): An engine in which the fuel is ignited by a spark from a spark plug in the cylinder, rather than by compression; spark from a spark plug; a gasoline engine.

Specific gravity: the mass (or weight) of a unit volume of any substance at a specified temperature compared to the mass of an equal volume of pure water at a standard temperature.

Stand (of trees): A tree community that possesses sufficient uniformity in composition, constitution, age, spatial arrangement, or condition to be distinguishable from adjacent communities.

Starch: A molecule composed of long chains of a-glucose molecules linked together (repeating unit $C_{12}H_{16}O_5$); these linkages occur in chains of a-1,4 linkages with branches formed as a result of a-1,6 linkages; widely distributed in the vegetable kingdom and is stored in all grains and tubers (swollen underground plant stems): this polymer is highly amorphous, making it more readily attacked by human and animal enzyme systems and broken down into glucose; gross heat of combustion: Qv(gross)=7560 Btu/lb.

Steam turbine: A device for converting energy of high-pressure steam (produced in a boiler) into mechanical power which can then be used to generate electricity.

Straight vegetable oil (SVO): Any vegetable oil that has not been optimized through the process of transesterification; using this type of vegetable oil in a diesel engine requires an engine modification that heats the oil before it reaches the fuel injectors.

Sustainable: An ecosystem condition in which biodiversity, renewability, and resource productivity are maintained over time.

Sustainable development: Often described as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The term describes development with an equitable balance between environmental, social and economic objectives.

Suspension: A dispersion of a solid in a gas, liquid, or solid.

Sustainable: An ecosystem condition in which biodiversity, renewability, and resource productivity are maintained over time.

Sustainable Feedstock: Feedstock that is produced in a way that conserves an ecological balance by avoiding depletion of natural resources.

SVO: Straight vegetable oil; burns well in many diesel engines but does not start the engine and will coke in the injectors as a hot engine cools; a separate tank of petro diesel or biodiesel is often used during starting and stopping engine, and an electric valve allows transfer to the straight vegetable oil tank.

Switch grass (Switchgrass): Prairie grass native to the United States and known for its hardiness and rapid growth, often cited as a potentially abundant feedstock for ethanol.

Syngas: A mixture of carbon monoxide (CO) and hydrogen (H_2) which is the product of high temperature gasification of organic material such as biomass; after clean-up to remove any impurities such as tars, syngas) can be used to synthesize organic molecules such as synthetic natural gas (SNG, methane (CH_4)) or liquid biofuels such as gasoline and diesel fuel via the Fischer-Tropsch process.

Synthesis gas: A mixture of carbon monoxide and hydrogen; see Syngas.

Synthetic crude oil (syncrude): a hydrocarbon product produced by the conversion of coal, oil shale, or tar sand bitumen that resembles conventional crude oil; can be refined in a petroleum refinery.

Tallow: Another name for animal fat, which can be used as a feedstock for biodiesel production.

Thermal Conversion: A process that uses heat and pressure to break apart the molecular structure of organic solids.

Thermochemical conversion: Use of heat to chemically change substances from one state to another, e.g. to make useful energy products.

Timberland: Forest land that is producing or is capable of producing crops of industrial wood, and that is not withdrawn from timber utilization by statute or administrative regulation.

Tipping fee: A fee for disposal of waste.

Titration: Applied to biodiesel, titration is the act of determining the acidity of a sample of waste vegetable oil by the drop-wise addition of a known base to the sample while testing with pH paper for the desired neutral reading (pH =7); the amount of base needed to neutralize an amount of waste vegetable oil determines how much base to add to the entire batch.

Ton (short ton): 2,000 pounds.

Tonne (Imperial ton, long ton, shipping ton): 2,240 pounds; equivalent to 1,000 kilograms or in crude oil terms about 7.5 barrels of oil.

Topping cycle: A cogeneration system in which electric power is produced first. The reject heat from power production is then used to produce useful process heat.

Topping and back pressure turbines: Turbines which operate at exhaust pressure considerably higher than atmospheric (non-condensing turbines); often multistage with relatively high efficiency.

Transesterification: The chemical process in which an alcohol reacts with the triglycerides in vegetable oil or animal fats, separating the glycerin and producing biodiesel; a process that transforms raw vegetable oil into biodiesel.

Traveling grate: A type of furnace in which assembled links of grates are joined together in a perpetual belt arrangement. Fuel is fed in at one end and ash is discharged at the other.

Trillion: 1×10^{12}

Turbine: A machine for converting the heat energy in steam or high temperature gas into mechanical energy. In a turbine, a high velocity flow of steam or gas passes through successive rows of radial blades fastened to a central shaft.

Turn down ratio- The lowest load at which a boiler will operate efficiently as compared to the boiler's maximum design load.

Ultimate Analysis: The determination of the elemental composition of the organic portion of carbonaceous materials, as well as the total ash and moisture; a description of a fuel's elemental composition as a percentage of the dry fuel weight as determined by prescribed methods; see American Society for Testing and Materials.

Ultra low sulfur diesel (ULSD): Ultra low sulfur diesel describes a new EPA standard for the sulfur content in diesel fuel sold in the United States beginning in 2006 – the allowable sulfur content (15 ppm) is much lower than the previous US standard (500 ppm), which not only reduces emissions of sulfur compounds (blamed for acid rain), but also allows advanced emission control systems to be fitted that would otherwise be poisoned by these compounds.

Uronic acid:- A simple sugar whose terminal $-CH_2OH$ group has been oxidized to an acid, COOH group; uronic acids occur as branching groups bonded to hemicelluloses such as xylan.

Vacuum distillation: A secondary distillation process which uses a partial vacuum to lower the boiling point of residues from primary distillation and extract further blending components.

Viscosity: a measure of the ability of a liquid to flow or a measure of its resistance to flow; the force required to move a plane surface of area 1 square meter over another parallel plane surface 1 meter away at a rate of 1 meter per second when both surfaces are immersed in the fluid; the higher the viscosity, the slower the liquid flows; methanol and ethanol ha a low viscosity while waste vegetable oil has a high viscosity. .

VOCs: see Volatile Organic Compounds.

Volatile organic compounds (VOCs): Name given to light organic hydrocarbons which escape as vapor from fuel tanks or other sources, and during the filling of tanks. VOCs contribute to smog.

Volatility: Propensity of a fuel to evaporate.

Waste streams - Unused solid or liquid by-products of a process.

Waste vegetable oil (WVO): Grease from the nearest fryer which is filtered and used in modified diesel engines, or converted to biodiesel through the process of transesterification and used in any diesel car; the usual starting product for the making of biodiesel; may be hot-water-washed for use as straight vegetable oil (SVO).

Water-cooled vibrating grate: A boiler grate made up of a tuyere grate surface mounted on a grid of water tubes interconnected with the boiler circulation system for positive cooling; the structure is supported by flexing plates allowing the grid and grate to move in a vibrating action; ash is automatically discharged.

Watershed: The drainage basin contributing water, organic matter, dissolved nutrients, and sediments to a stream or lake.

Watt: The common base unit of power in the metric system; one watt equals one joule per second, or the power developed in a circuit by a current of one ampere flowing through a potential difference of one volt. One Watt = 3.412 Btu/hr.

Wet mill: An ethanol production facility in which the corn is first soaked in water before processing; in addition to ethanol, wet mills have the ability to produce co-products such as industrial starch, food starch, high fructose corn syrup, gluten feed and corn oils.

Wheeling: The process of transferring electrical energy between buyer and seller by way of an intermediate utility or utilities.

Whole tree chips: Wood chips produced by chipping whole trees, usually in the forest and which contain both bark and wood; frequently produced from the low-quality trees or from tops, limbs, and other logging residues.

Whole tree harvesting: A harvesting method in which the whole tree (above the stump) is removed.

Wood: A solid lignocellulosic material naturally produced in trees and some shrubs, made of up to 40 to 50 percent cellulose, 20 to 30 percent hemicellulose, and 20 to 30 percent lignin.

Wood alcohol: see Methanol.

Wort: An oatmeal-like substance consisting of water and mash barley in which soluble starch has been turned into fermentable sugar during the mashing process – the liquid remaining from a brewing mash preparation following the filtration of fermentable beer.

Xylan: A polymer of xylose with a repeating unit of $C_5H_8O_4$, found in the hemicellulose fraction of biomass – can be hydrolyzed to xylose.

Xylose: A five-carbon sugar $C_5H_{10}O_5$; a product of hydrolysis of xylan found in the hemicellulose fraction of biomass.

Yarding: The initial movement of logs from the point of felling to a central loading area or landing.

Yeast: Any of various single-cell fungi capable of fermenting carbohydrates; bioethanol is produced by fermenting sugars with yeast.

Yellow grease: A term from the rendering industry – usually means used frying oils from deep fryers and restaurants' grease traps; can also refer to lower-quality grades of tallow from rendering plants.

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